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**CORNELL-DUBILIER ELECTRONICS SUPERFUND SITE
SOUTH PLAINFIELD, NEW JERSEY**

**DRAFT
FEASIBILITY STUDY REPORT
OPERABLE UNIT 3: GROUNDWATER**

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- D. Middlesex County Utility Authority Temporary Discharge Application
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- F. Source Area Thermal Treatment Estimate from TerraTherm

List of Acronyms and Abbreviations

°C	Degrees Celsius
°F	Degrees Fahrenheit
ARAR	Applicable or Relevant and Appropriate Requirements
ATSDR	Agency for Toxic Substances and Disease Registry
bgs	below ground surface
BHHRA	Baseline Human Health Risk Assessment
CDE	Cornell-Dubilier Electronics, Inc.
CEA	Classification Exception Area (for groundwater)
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980
cis-DCE	cis-1,2-Dichloroethene
COC	Chemical of Concern
COPC	Chemical of Potential Concern
CTE	Central Tendency Exposure
DFN	Discrete Fracture Network
DHE	Dehalococcoides Ethenogenes
DNAPL	Dense Non-Aqueous Phase Liquid
DO	Dissolved Oxygen
DUS	Dynamic Underground Stripping
EPM	Equivalent Porous Medium
ERH	Electrical Resistance Heating
ERT	Environmental Response Team (USEPA)
EVO	Emulsified Vegetable Oil
FS	Feasibility Study
gpm	Gallons per minute
GRA	General Response Action
HI	Hazard Index

List of Acronyms and Abbreviations

HPO	Hydrous Pyrolysis Oxidation
HQ	Hazard Quotient
ISCO	In Situ Chemical Oxidation
ISTD	In Situ Thermal Desorption
LBG	Louis Berger Group, Inc.
msl	Mean sea level
NAWC	Naval Air Warfare Center (former)
NCP	National Contingency Plan
NJAC	New Jersey Administrative Code
NJDEP	New Jersey Department of Environmental Protection
NJPDES	New Jersey Pollutant Discharge Elimination System
NPL	National Priorities List
O&M	Operations and Management
OMB	Office of Management and Budget
ORP	Oxidation Reduction Potential
OSWER	Office of Solid Waste and Emergency Response
OU	Operable unit
PAH	Polycyclic aromatic hydrocarbon
PbB	Blood Lead Level
PCB	Polychlorinated biphenyl
pg/L	Picogram per Liter
POTW	Publicly Owned Treatment Works
PRB	Permeable Reactive Barrier
PRG	Preliminary Remediation Goal
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
RME	Reasonable Maximum Exposure
ROD	Record of Decision

List of Acronyms and Abbreviations

SARA	Superfund Amendments and Reauthorization Act of 1986
SEAR	Surfactant Enhanced Aquifer Remediation
SEE	Steam-Enhanced Extraction
SVE	Soil Vapor Extraction
SVOC	Semi-volatile organic compound
TBC	To Be Considered
TCDD	Tetrachlorodibenzo- <i>p</i> -dioxin
TCE	Trichloroethylene; trichloroethene
TCH	Thermal Conduction Heating
TDA	Temporary Discharge Approval
TEQ	Toxic equivalence
TI	Technical Impracticability
TIER	Technical Impracticability Evaluation Report
TOC	Total Organic Carbon
TSDF	Treatment, Storage, and Disposal Facility
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
VOC	Volatile organic compound

Executive Summary

ES.1 Introduction

Purpose

The purpose of this feasibility study (FS) is to assemble and evaluate remedial alternatives for Operable Unit (OU) 3 of the Cornell-Dubilier Electronics (CDE) Superfund Site (Site) [EPA ID: NJD981557879] located in South Plainfield, New Jersey. OU3 addresses the contaminated groundwater portion of the Site. This FS was conducted on behalf of the U. S. Army Corps of Engineers (USACE), Kansas City District and the United States Environmental Protection Agency (USEPA), Region II.

The FS was prepared in compliance with the requirements of the Comprehensive Environmental Response, Compensation, and liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA). The FS follows guidance outlined in the USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERLCA* (USEPA, 1988). Together with the Remedial Investigation (RI) of OU3 and the Baseline Human Health Risk Assessment (BHHRA) for OU3 (Louis Berger Group, Inc. [LBG] and Malcolm Pirnie, 2011) the FS forms the basis for developing, evaluating, and selecting remedies for OU3.

Site Location and Background

Cornell-Dubilier Electronics, Inc. operated from 1936 to 1962, manufacturing electronic parts and components, including capacitors. The company allegedly released material contaminated with polychlorinated biphenyls (PCBs) and other hazardous substances, including chlorinated solvents, directly onto the soil during its operations. USEPA detected PCBs in the groundwater, soil, and in building interiors at the former CDE facility and at nearby residential, commercial and municipal properties. USEPA also detected PCBs in the surface water and sediments of Bound Brook, which is adjacent to the former CDE facility's southeast corner. The Site has been divided into four Operable Units (OUs) by the USEPA. Operable Unit 1 (OU1) addresses residential, commercial, and municipal properties in the vicinity of the former CDE manufacturing facility (the former CDE facility) at 333 Hamilton Boulevard. The USEPA signed a Record of Decision (ROD) for OU1 in 2003. Operable Unit 2 (OU2) addresses contaminated soil and buildings at the former CDE facility. The USEPA signed a ROD for OU2 in 2004. OU3 addresses contaminated groundwater and Operable Unit 4 (OU4) addresses Bound Brook.

ES.2 Remedial Investigation Results

The OU3 Remedial Investigation (RI) concluded that the following classes of chemical compounds were the primary contaminants of concern (COCs):

- VOCs, particularly chlorinated ethenes
- PCBs
- Inorganics
- PCBs -like Dioxins and Furans
- Pesticides
- SVOCs

VOCs were the primary COCs used to define the extent of contamination due to their relative mobility in groundwater. In addition, because of the magnitude of the historical VOC groundwater concentrations at the former CDE facility, it was anticipated that their extent would be greater than or equal to the other COCs.

The RI found that dense non-aqueous phase liquids (DNAPL), comprised predominantly of VOCs (chlorinated ethenes), entered the bedrock groundwater through the overburden. Over time, dissolution enhanced by groundwater advection and diffusion-driven mass transfer from the groundwater into the rock matrix has reduced the amount of DNAPL in the source area. Reactive liner data showed that DNAPL was only present at the source area (MW-14S). This was confirmed during OU2 soil remedial activities when product was observed at the bedrock surface during excavation efforts. The residual DNAPL in soils was removed as part of OU2 activities, and a relatively small fraction of residual DNAPL likely remains in fractured rock. Rock matrix results show that a large amount of contaminant mass has diffused into the rock matrix. These data show that the aqueous contaminant mass down gradient of the facility is the result of advective transport of dissolved mass and potential back diffusion out of the rock matrix, and is likely not the result of active DNAPL migration.

The highly conductive fracture network allows for the vertical and horizontal advection of groundwater and aqueous VOC mass. Because the fracture network is so pervasive, it provides a relatively large surface area for the VOCs to sorb onto and then diffuse into the rock matrix. The pore volume of the rock matrix is nearly two orders of magnitude larger than the fracture network, allowing it to hold the majority of the contaminant mass. Once the aqueous contaminant mass has diffused into the rock, it is left nearly immobile because of the low hydraulic conductivity of the rock matrix. However, there is a continual exchange of contaminant mass with passing groundwater driven by concentration gradients. In addition to sorption and diffusion, microbiological analyses indicate that the degradation of CVOCs is occurring, which contributes to the retardation of the advance rate of the leading edge of aqueous contaminant mass.

The aqueous contaminant mass migration has also been influenced by historical intermittent pumping at Spring Lake, which took place between 1964 and 2003, intermittent pumping at the Tingley Lane wellfield, and by ongoing withdrawals at the Park Avenue wellfield. Although the general direction of groundwater movement beneath the former CDE facility is to the north-northwest, the pumping centers to the north and east of the former CDE facility redirected the groundwater movement and mass transport. Today, groundwater extraction at the Park Avenue wellfield, along with potential groundwater discharges to Bound Brook and Spring Lake, are the dominant hydraulic influences on the regional and local hydrogeology.

When Spring Lake pumping ceased in 2003, the groundwater flow regime began to revert to a condition similar to the previous hydrogeologic regime dominated by the Park Avenue wellfield. Groundwater levels rose nearly five feet at the former CDE facility (this water level rise may not be entirely due to cessation of pumping at Spring Lake, but could also have resulted from potential increased recharge), Bound Brook became a potential gaining stream, and groundwater movement near the former CDE facility shifted to the northwest, rather than north to Spring Lake. In addition, the flow field to the north of Bound Brook shifted to the northeast due to ongoing groundwater extraction at the Park Avenue wellfield. These changes in conditions likely resulted in advective redistribution of the aqueous contaminant mass. In areas where concentrations of aqueous contaminants in fractures are greater than those in the adjacent matrix pore water, contaminant diffusion into the rock occurs, attenuating advective distribution of the aqueous contaminant mass. Furthermore, back diffusion of contaminants out of the matrix (pore water) occurs in areas where the contaminant concentration gradient between the rock matrix and the aqueous phase in fractures supports the process, which may contribute to ongoing groundwater contamination over a very long period of time (usually in multi-decade-to-multi-century timeframes). As a result, the contaminated aquifer cannot be restored to its highest beneficial use (potable water supply) in a reasonable timeframe and at a reasonable cost.

In support of the RI/FS process, contaminant (chlorinated VOC) fate and transport modeling was conducted to evaluate the extent of contaminant migration in the bedrock groundwater and the impact of potential source treatment remedies. Fate and transport simulations conducted using the FRACTRAN model showed that contaminant migration in the fracture network is much slower than groundwater flow rates in fractures, due to attenuation processes including diffusion of mass from fractures to the rock matrix. The effects of source removal were also modeled and the results show little impact from complete removal of source mass input on persistence of the downgradient plume, which may be expected given that the majority of the contaminant mass exists in the rock matrix. While some minor improvements in groundwater quality internally within the plume are achieved from complete source removal or cutoff, the time to achieve such benefits are extremely long and concentrations still remain elevated for very long time periods (i.e., on the order of several hundred years). These simulations also suggest

efforts to completely remove source inputs would have negligible impact on conditions nearer the plume front within any reasonable timeframe.

ES.3 Remedial Action Objectives

As indicated in the USEPA document *Technical Impracticability Decisions for Ground Water at CERCLA Response Action and RCRA Corrective Action Sites* (USEPA, 1998), a NAPL release in fractured sedimentary bedrock is an example of site conditions that may pose technical limitations to aquifer restoration. At OU3, the RI demonstrated that a significant portion of the contaminant mass now resides in the low-permeability rock matrix where groundwater is nearly immobile; therefore, implementation of remedial technologies that are typically capable of removing mass from the fractures only is futile due to back diffusion.

While evaluating potential remedial technologies for this FS, the technical feasibility of aquifer restoration was also evaluated. Based upon the findings of the potential for aquifer restoration, it was concluded that a waiver of the groundwater Applicable or Relevant and Appropriate Requirements (ARARs) is recommended due to technical impracticability (TI). A stand-alone TI Evaluation Report (TIER) was prepared to document the need to waive ARARs. The TIER documents the specific ARARs being waived and the area where a TI waiver is needed.

Wells used to supply groundwater for potable and non-potable uses are located within a 1-mile radius of the former CDE facility. When restoration of groundwater to beneficial uses is not practicable, USEPA expects to prevent further migration of contaminants, prevent exposure to the contaminated groundwater, and evaluate further risk reduction. The RAOs for OU3 were developed to satisfy these expectations with respect to prevention of exposure to contaminated groundwater via direct contact, ingestion, or inhalation. The RAOs for OU3 are as follows:

- Prevent migration of contaminants to areas beyond the TI zone.
- Reduce the potential human health and ecological risks to receptors from exposure by contact, ingestion, or inhalation of contaminated groundwater.

ES.4 Remedial Alternatives

Potential remedial technologies were screened based on the criteria of effectiveness, implementability, and relative cost. Development of remedial alternatives was conducted according to the requirements identified in CERCLA, as amended, and to the extent possible, the National Contingency Plan (NCP). The following six alternatives were proposed for the groundwater at OU3.

Alternative 1: No Action

Alternative 1 was developed from the NCP provision that requires consideration of a limited or no action response to serve as a baseline for evaluating other remedial alternatives. The No Action response does not include any containment, removal, disposal, or treatment of contaminated groundwater. In accordance with OSWER Directive 9283.1-33 (June, 2009), it also does not include new or existing institutional controls. Existing monitoring wells would remain in place. Any improvement of groundwater quality would be through natural attenuation including biodegradation, adsorption or diffusion into the rock matrix, dispersion, and dilution. Because hazardous contaminants remain at the Site under this alternative, five-year remedy reviews are required under CERCLA Section 121(c). Therefore, groundwater monitoring is required under this alternative to provide data to prepare the five-year remedy reviews.

Alternative 2: Monitored Natural Attenuation (MNA) with Institutional Controls (ICs)

Alternative 2 was developed to demonstrate reduction of contaminant concentrations by natural processes. Alternative 2 relies on natural mechanisms including dispersion, diffusion, dilution, adsorption, and biodegradation to reduce concentrations of contaminants in groundwater. Comprehensive monitoring is a required component to evaluate and verify the progress of MNA, as is a contingency plan that defines the appropriate response actions(s) should MNA not perform as expected. Institutional controls would be implemented to prevent or reduce exposure to hazardous substances. A groundwater CEA would be established in accordance with New Jersey regulations. Because hazardous contaminants remain at the Site under this alternative, five-year remedy reviews are required under CERCLA Section 121(c).

Alternative 3: Source Area Hydraulic Control at the former CDE facility using Groundwater Extraction Wells (includes MNA and ICs)

This alternative involves controlling the discharge of contaminated groundwater from the source area (defined as the former CDE facility boundary for this alternative), thereby reducing contaminant mass flux from the former CDE facility to down gradient areas/receptors. Alternative 3 also includes MNA and ICs, as discussed in Alternative 2. Hydraulic control of groundwater would be accomplished by extracting contaminated groundwater at a rate of approximately 40 gallons per minute (gpm) via two vertical extraction wells, each approximately 130 feet deep. Two discharge options are evaluated for treated groundwater: discharge to MCUA (Alternative 3a) and discharge to Bound Brook (Alternative 3b).

Alternative 4: Source Area Thermal Treatment (includes MNA and ICs) at the former CDE facility

The conceptual design for Alternative 4 involves thermal treatment using two thermal treatment process options: thermal conductive heating (TCH) (also known as in-situ thermal desorption (ISTD)) and steam-enhanced extraction (SEE). The goal is to remove

contaminant mass from the source area located at the former CDE facility to reduce contaminant mass flux from the former CDE facility. This alternative would be accomplished by installing and operating heater wells, vapor/multi-phase extraction wells, and steam injection wells to vaporize/desorb VOCs from the subsurface and bring them to the surface for treatment. Alternative 4 includes implementation of institutional controls as well as detailed monitoring for natural attenuation, as discussed for Alternative 2.

Alternative 5: Source Area In Situ Chemical Oxidation (includes MNA and ICs) at the former CDE facility

The conceptual design for Alternative 5 involves in-situ chemical oxidation (ISCO) at the former CDE facility with high pH-activated sodium persulfate, which would oxidize the chlorinated ethenes in the injection area. The goal is to remove contaminant mass from the source area located at the former CDE facility to reduce contaminant mass flux from the former CDE facility. It is expected that the ISCO applications will treat most of the contaminant mass present in the rock fractures, but only a portion of contaminant mass present in the rock matrix. This alternative would be accomplished by installing injection wells and injecting persulfate quarterly for a period of five years. Alternative 5 includes implementation of institutional controls as well as detailed monitoring for natural attenuation, as discussed for Alternative 2.

Alternative 6: Source Area In Situ Bioremediation (includes MNA and ICs) at the former CDE facility

The conceptual design for Alternative 6 involves *in situ* bioremediation via enhanced anaerobic biodegradation at the former CDE facility. Bench microcosm studies performed during the RI demonstrated that, under optimal conditions for anaerobic biodegradation (i.e., addition of carbon substrate and nutrients), complete transformation of TCE to ethene occurred in groundwater samples. The complete dechlorination of TCE to ethene indicates that dechlorinating bacteria are naturally present at these locations. The conditions required for anaerobic biodegradation of chlorinated ethenes may be created in the field by adding carbon substrates that are fermented by a wide variety of organisms, producing hydrogen gas. The hydrogen gas may then be used by dechlorinating bacteria as an electron donor in the reductive dechlorination of chlorinated ethenes.

This alternative would be accomplished by installing injection wells and injecting emulsified vegetable oil (EVO) annually for ten years. The EVO applications will treat most of the contaminant mass present in the rock fractures but only a fraction of contaminant mass present in the rock matrix (through back-diffusion to the fractures). Therefore, after the completion of bioremediation treatment, detailed MNA monitoring would be performed for a timeframe similar to that described in Alternative 2 (i.e., on the order of decades or centuries).

ES.5 Comparative Analysis of Remedial Alternatives

Overall Protection of Human Health and the Environment

With the exception of Alternative 1 (No Action), all of the alternatives include institutional controls to mitigate identified potential risks resulting from exposure to groundwater through pathway elimination. Therefore, Alternatives 2 through 6 would be protective of human health and the environment. Alternative 1 would not be protective of human health and the environment since it does not include measures to prevent exposure to groundwater.

Compliance with ARARs

A TI Zone has been established to capture OU3 and ARARs have been waived within the TI Zone.

Long-Term Effectiveness and Permanence

As discussed previously, the FRACTRAN model results indicate that source area treatment will have little impact on the persistence of the downgradient plume. While some minor improvements in groundwater quality within the plume are achieved from source area treatment, the time to achieve these benefits is very long and concentrations still remain elevated for very long time periods (i.e., on the order of several hundred years).

The long-term effectiveness of natural attenuation processes was evaluated using the FRACTRAN model. The model results indicate that chlorinated ethenes will persist at concentrations exceeding ARARs for very long time periods. However, the expectation is that the rate of plume front migration is very slow due to the effects of matrix diffusion. Therefore, although Alternatives 3, 4, 5, and 6 may locally improve groundwater quality, the long-term effectiveness of all the alternatives, including Alternative 2 (MNA with ICs), would be equal.

Reduction of Toxicity, Mobility, and Volume

Alternatives 4 (Thermal Treatment), 5 (ISCO), and 6 (Bioremediation) would all partially meet the preference in CERCLA for treatment on site and would result in a reduction in the volume of COCs in the MW-14 area, and at least a temporary reduction in mobility of COCs to downgradient portions of the plume. Alternative 3 (Hydraulic Control), would result in a reduction of mobility to downgradient portions of the plume as long as the system is in operation. Of these alternatives, Alternative 4 would likely be the most effective overall. However, as it has been demonstrated that source removal at plumes in fractured sedimentary rock will not likely improve conditions downgradient in the plume, all of the alternatives, including Alternative 2 (MNA with ICs), would be equal equally effective at reducing toxicity, mobility, and volume of the entire OU3 area.

Short-Term Effectiveness

Alternatives 3 (Hydraulic Control), 4 (Thermal Treatment), and 5 (ISCO) would involve construction and/or in-situ treatment hazards that could pose a risk to site workers or the surrounding environment. However, it is anticipated that these risks could be mitigated through the use of engineering controls, safe work practices, and personal protective equipment. All of the alternatives except Alternative 1 (No Action) involve the drilling and sampling of monitoring wells, which is expected to pose minimal risks to site workers and the surrounding environment.

Implementability

Alternative 2 (MNA with ICs) could be readily implemented using commonly available technologies and with minimal design or permitting. Alternatives 3 (Hydraulic Control), 5 (ISCO), and 6 (Bioremediation) could also be readily implemented; however, all three would require permitting (underground injection or surface water/sewer discharge). Alternatives 5 and 6 would require some design as well as bench and/or field-scale pilot testing, while Alternative 3 would require full-scale plans and specifications for construction of the groundwater extraction and treatment infrastructure. Alternative 4 would likely be the most difficult to implement due to the energy, permitting, and heating controls/infrastructure required.

Cost

The costs for each alternative (except for Alternative 1) were developed on the basis of preliminary engineering designs to meet the RAOs. The estimated present value costs range from \$2.1 million for Alternative 1 to \$39 million for Alternative 3 (sewer discharge scenario).

1. Introduction

1.1. Purpose

The purpose of this feasibility study (FS) is to assemble and evaluate remedial alternatives for Operable Unit (OU) 3 of the Cornell-Dubilier Electronics (CDE) Superfund Site (Site) [EPA ID: NJD981557879] located in South Plainfield, New Jersey. OU3 addresses the contaminated groundwater portion of the Site. This FS was conducted on behalf of the U. S. Army Corps of Engineers (USACE), Kansas City District and the United States Environmental Protection Agency (USEPA), Region II.

The FS was prepared in compliance with the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA). The FS follows guidance outlined in the USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (USEPA, 1988). Together with the Remedial Investigation (RI) of OU3 and the Baseline Human Health Risk Assessment (BHHRA) for OU3 (Louis Berger Group, Inc. [LBG] and Malcolm Pirnie, 2011) the FS forms the basis for developing, evaluating, and selecting remedies for OU3. The FS involves the following general steps:

- Identifying remedial action objectives (RAOs) based on Applicable or Relevant and Appropriate Requirements (ARARs);
- Identifying general response actions;
- Identifying potential treatment and containment technologies and the associated process options;
- Screening the various technologies and process options based on their effectiveness, implementability, and cost;
- Assembling the selected technologies and process options into remedial alternatives for remediation of contaminants at OU3; and
- Performing a detailed analysis of the remedial alternatives by assessing them against seven evaluation criteria (evaluation against the state acceptance and community acceptance criteria is performed following comment on the FS report).

1.2. Report Organization

This report is organized into seven sections. A brief description of each section follows:

Section 1.0, INTRODUCTION, presents an overview of Site background information including a description and history of the site, site geologic and hydrogeologic conditions, and the site's hydrology, ecology, and demographics.

Section 2.0, REMEDIAL INVESTIGATION FINDINGS, presents a summary of the nature and extent of contamination, contaminant fate and transport, a summary of human health risks, and the site conceptual model.

Section 3.0, REMEDIAL ACTION OBJECTIVES AND GENERAL RESPONSE ACTIONS, provides a discussion of the ARARs associated with the Site, a description of the preliminary remediation goals (PRGs) selected to meet the RAOs, and identification of the RAOs. In addition, general response actions (GRAs) capable of meeting the RAOs are discussed.

Section 4.0, EVALUATION AND SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS, presents a review of remedial technologies and process options that may be utilized for the general response actions identified in Section 2. The technologies are screened for applicability for use in developing remedial alternatives for OU3.

Section 5.0, ASSEMBLY OF REMEDIAL ALTERNATIVES, presents the development and conceptual description of remedial alternatives.

Section 6.0, DETAILED EVALUATION OF REMEDIAL ALTERNATIVES, provides a detailed analysis of the remedial alternatives. Each alternative is evaluated based on its overall protection of human health and the environment, compliance with ARARs, long-term effectiveness, reduction of toxicity, mobility, and volume, short-term effectiveness, implementability, and cost.

Section 7.0, REFERENCES, identifies reference documents used for the preparation of this FS report.

The following sub-sections provide an overview of the Site location and background, a summary of previous Site investigations, and descriptions of the key physical attributes, surrounding land uses, and demographics.

1.3. Background and Setting

Cornell-Dubilier Electronics, Inc. operated at 333 Hamilton Boulevard from 1936 to 1962, manufacturing electronic parts and components, including capacitors. The company allegedly released material contaminated with polychlorinated biphenyls (PCBs) and other hazardous substances, including chlorinated solvents, directly onto the

soil during its operations. USEPA detected PCBs in the groundwater, soil, and in building interiors at the former CDE facility and at nearby residential, commercial and municipal properties. USEPA also detected PCBs in the surface water and sediments of Bound Brook, which is adjacent to the former CDE facility's southeast corner. The Site has been divided into four Operable Units (OUs) by the USEPA. Operable Unit 1 (OU1) addresses residential, commercial, and municipal properties in the vicinity of the former CDE manufacturing facility (the former CDE facility) at 333 Hamilton Boulevard. The USEPA signed a Record of Decision (ROD) for OU1 in 2003. Operable Unit 2 (OU2) addresses contaminated soil and buildings at the former CDE facility. The USEPA signed a ROD for OU2 in 2004. OU3 addresses contaminated groundwater and Operable Unit 4 (OU4) addresses Bound Brook.

As such, the following terminology will be used throughout this report:

The **"Site"** refers to all four OUs which comprise the CDE Superfund Site, and the extent of each OU investigation;

The **"former CDE facility"** refers to the physical extent of the industrial park operated at 333 Hamilton Boulevard. This is approximately equivalent to the extent of OU2; and

"OU3" refers to the geographic extent of the groundwater contamination and associated investigation.

The former CDE facility is located at 333 Hamilton Boulevard in the Borough of South Plainfield, Middlesex County, in the central portion of New Jersey (Figure 1-1) and covers approximately 26 acres. Most recently, the property was known as the Hamilton Industrial Park, and contained numerous buildings. These buildings were demolished in 2008 following relocation of the industrial park tenants.

The Spicer Manufacturing Company operated a manufacturing plant on the property from 1912 to 1929. They manufactured universal joints and drive shafts, clutches, drop forgings, sheet metal stampings, screw products, and coil springs for the automobile industry. The plant included a machine shop, box shop, lumber shop, scrap shop, heat treating building, transformer platform, forge shop, shear shed, boiler room, acid pickle building, and die sinking shop. A chemical laboratory for the analysis of steel was added in 1917. Most of the major structures were erected by 1918. When the Spicer Manufacturing Company ceased operations at the facility, the property consisted of approximately 210,000 square feet of buildings (FWENC, 2002).

After the departure of the Spicer Manufacturing Company, CDE manufactured electronic components, including capacitors, from 1936 to 1962. It has been reported that the company also tested transformer oils for an unknown period of time. PCBs and chlorinated organic degreasing solvents were used in the manufacturing process, and it has been alleged that during CDE's period of operation, the company disposed of PCB-contaminated materials and other hazardous substances at the facility. It has been

reported that the rear of the property was saturated with transformer oils and capacitors were also buried behind the facility during the same time period (FWENC, 2002).

Since CDE's departure from the facility in 1962, it has been operated as a rental property consisting of commercial and light industrial tenants. Numerous tenants have occupied the complex. In 2007, the USEPA began implementing the OU2 ROD with the relocation of the tenants at the industrial park and demolition of the 18 buildings. Relocation of the tenants was completed in mid-2007, demolition of buildings was completed in May 2008, and OU2 soil remedial activities are ongoing. An aerial photograph of the CDE facility dating from 2007, showing the locations of former buildings, is included as Figure 1-2.

The developed portion of the facility (the northwestern portion) comprised approximately 45 percent of the total land area and contained temporary asphalt capping following building demolition, a system of catch basins to channel stormwater flow, and paved roadways. Several of the catch basins drained into a stormwater collection system whose outfalls discharge at various locations along Bound Brook. The other 55 percent of the property was predominantly vegetated before the OU2 remedial activities began. The central part of the undeveloped portion was primarily an open field, with some wooded areas to the northeast and south, and a deteriorated, partially paved area in the middle of the undeveloped portion of the facility. The northeast and southeast boundaries consisted primarily of wetland areas adjacent to Bound Brook, which flows from the eastern corner across the northeastern border of the undeveloped portion of the facility (FWENC, 2002). Once OU2 remedial activities are completed (anticipated to be in late 2011), the entire former CDE facility will be covered by an asphalt cap with a stormwater collection system.

1.4. Site Location

The Site is located in the Borough of South Plainfield, northern Middlesex County, in the central portion of New Jersey. According to the 2006 Census estimate, South Plainfield has a population of approximately 22,795 people with a total land area of approximately 8.4 square miles (City-Data.com)

The Site includes a fenced, 26-acre facility that is bounded on the northeast by Bound Brook and the former Lehigh Valley Railroad, Perth Amboy Branch (presently Conrail); on the southeast by Bound Brook and a property used by the South Plainfield Department of Public Works; on the southwest, across Spicer Avenue, by single family residential properties; and to the northwest, across Hamilton Boulevard, by mixed residential and commercial properties. The area surrounding the former CDE facility represents an urban environment with principally commercial and light industrial use to the northeast and east, principally residential development to the south and directly north, and mixed residential and commercial properties to the west. In 2007, USEPA began implementing the OU2 ROD with the relocation of the tenants at the industrial park and demolition of the buildings at the former CDE facility. Relocation of the tenants was completed in

mid-2007, demolition of buildings was completed in May 2008, and OU2 soil remedial activities commenced in late 2008 and are ongoing.

1.5. Previous Investigations

Table 1-1 summarizes the project history and enforcement activities associated with the Site. Environmental conditions at the former CDE facility were first investigated by the New Jersey Department of Environmental Protection (NJDEP) in 1986. Subsequent sampling by the NJDEP and the USEPA showed the presence of PCBs, VOCs, and inorganic chemicals in facility soil, surface water, and sediment. In 1997, the USEPA conducted a preliminary investigation of Bound Brook and also collected surface soil and interior dust samples from nearby residential and commercial properties. These investigations led to fish consumption advisories for Bound Brook and its tributaries. As a result of these sampling activities, the Site was added to the National Priorities List (NPL) in July 1998. Between 1997 and 2000, the USEPA ordered several removal actions to be performed, including:

- Removal of PCBs in interior dust and removal of soil at residential properties located west and southwest of the former CDE facility.
- Paving driveways and parking areas, installing a security fence, and implementing drainage controls at the industrial park.

In 2000, a Remedial Investigation (RI) was conducted by Foster Wheeler Environmental Corporation (Foster Wheeler) that included collecting soil, sediment, and building surface samples, as well as installation and sampling 12 shallow bedrock monitoring wells (MW-01A, MW-02A, and MW-03 through MW-12) at the former CDE facility (FWENC, 2002). Shortly thereafter, the USEPA divided the Site into four OUs as described above, and issued RODs for OU1 and OU2, respectively, in September 2003 and September 2004.

The remedy specified in the ROD for OU2, which encompasses the former CDE facility, included the following components:

- Excavating an estimated 107,000 cubic yards of contaminated soil containing PCBs at concentrations greater than 500 parts per million (ppm) and contaminated soil that exceed New Jersey's Impact to Groundwater Soil Cleanup Criteria (IGWSCC) for contaminants other than PCBs;
- Treating (on the former CDE facility) excavated soils amenable to treatment by Low Temperature Thermal Desorption (LTTD), followed by backfilling of excavated areas with treated soil;
- Transporting contaminated soil and debris not suitable for LTTD treatment to an off-Site facility for disposal, with treatment as necessary;

- Excavating an estimated 7,500 cubic yards of contaminated soil and debris from the capacitor disposal areas (CDAs) and transporting for disposal off-Site, with treatment as necessary;
- Installing a multi-layer cap or hardscape;
- Installing engineering controls;
- Restoring the property; and,
- Implementing institutional controls.

In 2007, OU2 Remedial Action began with the removal of former CDE facility structures, followed by excavation, treatment, and/or removal of former CDE facility soils. The OU2 soil remedial activities are ongoing.

In January 2008, seven deep bedrock wells (ERT-1 through ERT-7) were drilled by the USEPA's Environmental Response Team (ERT) to assess the hydraulic properties of the fractured bedrock and water quality of the bedrock groundwater up- and down-gradient of the former CDE facility. The wells were drilled to an average depth of 150 feet below ground surface (bgs). In February 2008, one additional deep bedrock well (ERT-8) upgradient of the former CDE facility was also drilled. Prior to installation of these wells, groundwater VOC samples were collected from multiple depths using packer sampling techniques, targeting discrete water-bearing zones within each well. ERT-1 through ERT-6 and ERT-8 were completed in June 2008 with FLUTETM multi-port sampling devices. In August 2008, groundwater samples were collected from these seven FLUTETM wells¹ and the twelve shallow bedrock monitoring wells and were analyzed for VOCs, semi-volatile organic compounds (SVOCs), pesticides, PCB Aroclors, and metals. Figure 1-3 depicts the locations of the twelve shallow bedrock wells and eight deep bedrock wells that were present at OU3 as of 2008. The 2008 groundwater data are discussed in the OU3 RI report (LBG and Malcolm Pirnie, 2011b).

1.6. Physical Characteristics of the Site

The following is a general description of the physical characteristics of the Site.

1.6.1. Surface Features and Topography

Prior to ongoing OU2 remedial activities, the northwestern portion of the former CDE facility (comprising approximately 45% of the total facility acreage) contained 18 buildings that have since been demolished. The land in this northwestern portion was gently sloping, with pre-building demolition elevations ranging from 70 to 82 feet above mean sea level (msl).

¹ ERT-7 was not constructed as a FLUTETM well until September 2009; therefore, groundwater samples were not collected from ERT-7 in August 2008.

The remaining 55% of the land area was undeveloped and predominantly vegetated. The central part of the undeveloped portion was primarily a flat, open field, with some wooded areas to the south. A paved area in the middle of the former CDE facility is where capacitor-related debris had been observed. This area was relatively level, with pre-OU2 remediation elevations ranging from approximately 71 to 76 feet above msl. The property drops steeply to the northeast and southeast, and the eastern portion of the property consists primarily of wetlands bordering Bound Brook. Elevations in this area ranged from approximately 71 feet above msl at the top of the bank to approximately 60 feet above msl along Bound Brook (FWENC, 2001). Ongoing OU2 soil remediation activities at the former CDE facility have altered the surface topography. At the conclusion of OU2 remedial activities, the former CDE facility will be covered by an asphalt cap, gently sloping from the southwest to the northeast; storm water will be collected by a series of catch basins and a detention basin, and will ultimately discharge to Bound Brook.

1.6.2. Climate

The climate for Middlesex County is classified as temperate. Polar continental air masses control the region's winter weather and tropical air masses control summer weather. In the summer, these tropical air masses, largely originating over the Gulf of Mexico, travel about 1,000 miles over land before arriving in New Jersey. Although the heaviest rains are produced by coastal storms of tropical origin, a portion of the air masses originate from the Great Lakes. Prevailing winds are from the northwest from October through April, and from the southwest the remainder of the year.

In South Plainfield, the temperature ranges from an average of 29 degrees Fahrenheit (°F) in January to 75°F in July, with an average annual temperature of about 53°F (FWENC, 2002). Summer temperatures occasionally exceed 100°F and temperatures in the middle to upper 80's°F occur frequently. Winter temperatures generally are not below 20°F for long time periods (FWENC, 2002). The average annual precipitation is approximately 49 inches. Precipitation occurs fairly evenly throughout the year.

1.6.3. Geology

The Site lies within the Piedmont Physiographic Province of New Jersey (Fenneman, 1938). The following sections contain a brief description of the surficial and bedrock geology of the Site. More extensive information is presented in the OU3 RI report (LBG and Malcolm Pirnie, 2011b).

1.6.3.1. Surficial Geology

Quaternary and pre-Quaternary glacial and glacial-fluvial deposits overlie bedrock across much of the northern portion of New Jersey. Based on regional surficial geologic mapping for the area, unconsolidated deposits in the vicinity of the Site include sandy, silty clay to clayey, silty sand containing some shale, mudstone, and sandstone fragments. Surficial deposits underlying the Site are generally identified as regolith derived from

weathering of shale, mudstone, and sandstone. The unconsolidated deposits are up to 30 feet thick regionally, but are generally less than 10 feet thick in the vicinity of the Site (FWENC, 2002).

1.6.3.2. Bedrock Geology

The Site is located within the Newark Basin, which is a tectonic rift basin that covers roughly 7,500 square kilometers extending from southern New York through New Jersey and into southeastern Pennsylvania (Figures 1-4 and 1-5). The basin is filled with Triassic-Jurassic sedimentary and igneous rocks that are tilted, faulted, and locally folded.

The Passaic Formation (historically known as the Brunswick Formation) occupies an upper unit of the Newark Supergroup rocks in the Triassic-Jurassic Newark Basin and is the thickest and most aerially extensive unit in the Newark Basin (Herman, 2001). This formation consists of mostly red cyclical lacustrine clastics including mudstone, siltstone, and shale, with minor fluvial sandstone (Michalski and Britton, 1997). The reddish color originates from reworked hematite, which comprises 5-10% of the unit. The Site is located immediately south of the contact between the Passaic Formation mudstone unit and a thinly bedded sandstone and siltstone unit (Herman, 2001).

1.6.3.3. OU3 Geology

Unconsolidated deposits at the former CDE facility range in thickness from 0.5 to 15 feet and generally thicken to the east towards Bound Brook. Natural unconsolidated materials, consisting primarily of red-brown silt and sand with silt and clay layers, are generally intermixed with urban fill materials (including cinders, ash, brick, glass fragments, metal, and other detritus) throughout the former CDE facility and vicinity. A thin (surface to 15 feet bgs) layer of weathered bedrock overlies competent bedrock, consistent with the weathered bedrock identified by regional surficial geologic mapping. This material primarily consists of heavily weathered siltstone and shale material with a heterogeneous texture ranging from silt to fine sand, with some zones of angular, silty gravel and silty clay.

The top of competent bedrock underlying the former CDE facility ranges from 4 to 15 feet bgs, except in the northwestern portion of the former CDE facility where bedrock was present immediately beneath the former building foundations. Based on boring log data for wells installed during the OU3 RI, bedrock at the Site consists primarily of red-brown to dark brown mudstone, siltstone, and shale, consistent with the upper Passaic Formation. Boring logs from wells to the north of the former CDE facility are generally indicative of Passaic Formation mudstone facies, while cores from the facility and areas southwest and east of the facility show siltstone and shale. The bedrock units range from massive rock with few features to highly laminated beds. The bedrock units are consistently fine-grained in texture, with numerous calcified veins and vugs throughout. Bedrock associated with the older Lockatong and Stockton formations was not encountered in bedrock cores from OU3.

Bedrock boring logs and borehole acoustical televiewer data (presented in the RI report) indicate that numerous fracture zones are present in bedrock from the surface to approximately 600 feet bgs, the maximum drilled depth. The shallow bedrock units are heavily fractured and weathered, with significant shallow fracture in-filling with weathered material ranging in texture from silt/clay to sand. Shallow fractures are generally more open in the shallow bedrock and become less open with depth. The bedrock contains heavily fractured zones that occur along the bedding planes (parallel to sub-parallel). Weathered fracture zones within the bedrock ranged from near horizontal to near vertical. Pole to plan projections of the fracture data interpreted from acoustical televiewer data (presented in the RI report) show that the majority of these features are relatively low angle, ranging from 10 to 30 degrees from horizontal, consistent with the regional character of the Passaic Formation.

Based on the borehole geophysical data collected during the OU3 RI, the bedding planes of the bedrock units (less open features) in the vicinity of the former CDE facility generally strike 63 degrees East of North (N65E), and generally dip toward the northwest between 5 and 15 degrees. The predominant down-dip direction of fractures (more open features) is toward the northwest, parallel to sub-parallel to the dip of most bedding planes. A large fracture zone was encountered in MW-14 (67 feet bgs), MW-15 (76 feet bgs), MW-17 (180 to 210 feet bgs), and downgradient from the former CDE facility at MW-20 (302 feet bgs). However, no significant fracture zone was observed in MW-16, which lies between MW-14 (near the center of the former CDE facility) and MW-20 (downgradient). The orientation of the fracture zone was calculated (3-point solution) and is nearly parallel to regional bedding. This intensively fractured seam is characterized by significantly larger than average fracture apertures.

The aperture of each fracture was calculated using the borehole transmissivity data and the Cubic law equation (Bear, 1993). Approximately 3,900 apertures were calculated using this procedure during the RI. The average fracture aperture was calculated to be 83 microns. The fracture frequency, derived from the borehole transmissivity data and the acoustic televiewer logs, was calculated to be 0.9/linear foot.

1.6.4. Hydrogeology

The following sections provide a brief description of the regional and OU3-specific hydrogeology. More extensive information is presented in the RI report (LBG and Malcolm Pirnie, 2011b).

1.6.4.1. Regional Hydrogeology

The Passaic Formation generally forms tabular aquifers and confining units that are several tens of feet thick. Groundwater movement is primarily through bedding plane fractures and steeply dipping interconnected fractures and dissolution channels (secondary permeability). A very limited amount of groundwater flows through the interstitial pore spaces between silt or sand particles because of compaction and cementation of the formation (primary permeability). Differences in permeability

between layers resulting from variations in fracturing and weathering may account for many water-bearing units.

Groundwater in the Passaic Formation is often unconfined in the shallower, more weathered part of the aquifer; however, silt and clay derived from the weathering process typically fill fractures, thereby reducing permeability. This relatively low permeability surface zone reportedly extends 50 to 60 feet bgs (Michalski, 1990). Groundwater in the deeper portion of the Passaic Formation is generally confined. Recharge is by leakage through fractures in the confining units. The transmissivity of mudstone and siltstone units can range from 400 to 14,500 gallons per day per foot (Herman, 2001). Local and regional groundwater discharge boundaries include surface water bodies like Bound Brook. However, municipal pumping centers (water wells) account for most of the regional groundwater discharge.

The Passaic Formation contains an aquifer that is used as a source of potable water for some of the communities surrounding the former CDE facility (Figure 1-6). Numerous private, industrial, and municipal wells tap the formation, with reported pumping rates that range from a few to several hundred gallons per minute. Current groundwater extraction influences regional and local groundwater movement, and the variable historical configuration and pumping of municipal extraction wells exerted a dominant influence on historical groundwater movement at the former CDE facility. The following wellfields have been identified as having the most significant influence on that groundwater movement (details for these wellfields are presented in the RI report):

- Spring Lake Wellfield
- Park Avenue/Sprague Wellfield
- Tingley Lane Wellfield

1.6.4.2. OU 3 Hydrogeology

The bedrock aquifer in OU3 is separated into three hydrogeologic units or water-bearing zones, identified as the “shallow”, “intermediate”, and “deep” water bearing zones.

The shallow water bearing zone is unconfined and extends from the water table to a depth of approximately 120 feet bgs (bedrock). The water table fluctuates from the unconsolidated deposits into bedrock due to many factors including seasonal precipitation and the effects of nearby pumping. Therefore, the groundwater encountered in the unconsolidated deposits is interpreted as part of the shallow unconfined bedrock aquifer. The shallow water bearing zone is potentially hydraulically connected to surface water bodies such as Bound Brook, Cedar Creek, and Spring Lake. The intermediate and deep water bearing zones, located below 120 feet bgs, are confined.

Groundwater movement in the highly fractured shallow water bearing zone behaves like an equivalent porous medium (EPM) (e.g. sand and gravel aquifer). This is evidenced by the Theisian behavior of the aquifer in response to pumping during the Integrated

Pumping Test (LBG and Malcolm Pirnie, 2011b). Groundwater movement in the intermediate and deep water bearing zones also has some characteristics of an EPM; however, there is some evidence that the lack of horizontal and vertical fractures in some locations influence groundwater movement. Each of these water bearing units is described below.

Shallow water bearing zone: The shallow water bearing zone is monitored by the uppermost port in each of the multi-port systems and the shallow bedrock wells constructed at the former CDE facility. An evaluation of current shallow bedrock groundwater levels compared to those collected during previous investigations indicate that current shallow bedrock aquifer water levels are approximately five feet higher than they were during the Foster Wheeler RI (FWENC, 2001). The water level variations are interpreted to be the result of historical groundwater pumping near Spring Lake, which was gradually reduced and ultimately stopped in 2003.

Intermediate water bearing zone: The intermediate water bearing zone marks the transition between the shallow and deep water bearing zones. This zone is interpreted to be confined and is monitored by the ports in each of the multi-port systems between 120 feet and 160 feet bgs. The fractures in the intermediate water bearing zone exhibit less in-filling with sediment and exhibit an increased permeability in individual fractures as compared to the shallow water bearing zone.

Deep water bearing zone: The deep water bearing zone is confined and exhibits an increased permeability, due to fractures being more open with less in-filling of material due to weathering. This zone is monitored by the ports in each multi-port system between 200 and 240 feet bgs. This depth range was selected to characterize the deep water bearing zone because it has a dense network of ports, which facilitates data contouring and interpretation.

1.6.4.3. Hydraulic Gradient and Groundwater Movement

Water levels were measured during three synoptic rounds (October 2009, March 2010, and July 2010) and are presented in the RI report (LBG and Malcolm Pirnie, 2011b). Groundwater elevations measured in July 2010 at shallow wells and the shallowest multi-port sampler ports were used to characterize the shallow water bearing zone (Figure 1-7). The data show that the potentiometric surface is generally controlled by topography, with groundwater in the shallow water bearing zone potentially discharging to Bound Brook, Cedar Brook, and Spring Lake. Groundwater in the shallow water bearing zone forms a mound at the former CDE facility, moving north and east from the facility toward Bound Brook, and northwesterly toward the low-lying area at the confluence of Bound Brook and Cedar Brook. Groundwater elevations in wells MW-19, MW-20, and MW-21 in the northwestern portion of OU3 reflect the influence of the Park Avenue wellfield. To the northeast of the former CDE facility, immediately across Bound Brook, groundwater movement in the shallow water bearing zone is generally toward the west, with groundwater discharging to Bound Brook, Cedar Brook and Spring Lake.

A plot of groundwater elevations measured in July 2010 at multi-port sampler ports located between 120 and 160 feet bgs was used to characterize the intermediate water bearing zone (Figure 1-8). Groundwater movement in this zone is primarily to the north. There is potential groundwater-surface water interaction to the north of the former CDE facility at Bound Brook.

A plot of groundwater elevations measured in July 2010 at multi-port sampler ports between 200 and 240 feet bgs was used to characterize the deep water bearing zone (Figure 1-9). Groundwater movement in this zone is primarily to the north. A plot of the potentiometric surface indicates that the hydraulic gradient is more uniform in this zone, with no exhibited potential groundwater-surface water interaction.

A distinct, highly transmissive fracture zone was intersected by several boreholes during the RI. Most notably, this fracture zone underlies the suspected source area (MW-14) at a depth of 67 feet bgs, and is present at MW-20 at a depth of approximately 300 feet bgs and MW-17 at a depth of approximately 200 feet bgs. In the suspected source area, the highly transmissive fracture zone marks a sharp decrease in both rock matrix and aqueous chlorinated volatile organic compound (CVOC) concentrations (discussed in Section 2). At downgradient areas, the location of the fracture zone is coincident with the vertical axis of the observed CVOC aqueous mass. This suggests that the fracture zone limited vertical migration of the aqueous contaminant mass at the former CDE facility, and facilitated downgradient transport of the contaminant mass along a preferential (high transmissivity) pathway. While the bulk of mass transport probably occurs throughout the dense fracture network discussed previously, this single feature is significant enough to warrant additional discussion because it is significantly more transmissive than any other observed structural feature and was observed in borings near the suspected source area and near the Spring Lake wells.

A hydrogeologic cross section is presented as Figure 1-10. The synoptic data were collected from each multi-port sampler port in July 2010, and show the horizontal and vertical components to groundwater movement in the study area. The vertical gradient varies across the study area and with depth (Figure 1-11). Groundwater elevations measured at multiple depths at MW-13, MW-16, ERT-3, and ERT-4 indicate upward hydraulic gradients at wells adjacent to Bound Brook, with lower upward hydraulic gradients observed in wells at the former CDE facility, closer to the source area. When compared to the corresponding stream gage measurements, the hydraulic head difference indicates the potential for groundwater discharge to Bound Brook. The upward vertical hydraulic gradients in the deep water bearing zone wells to the north of the former CDE facility (MW-20, MW-19) are likely related to confined conditions and gradients created by groundwater extraction at the Park Avenue wellfield.

A comparison of historical groundwater elevations measured during the Foster Wheeler RI to the groundwater level measurements collected during the OU3 RI show a marked change in groundwater elevations and the direction of groundwater movement across OU3 in the shallow water bearing zone. Past groundwater elevations indicated that

groundwater movement in the shallow water bearing zone at OU3 was generally toward the northwest, with a potential for surface water to discharge from Bound Brook to the aquifer. Current conditions are just the opposite. Groundwater level measurements show shallow groundwater is potentially discharging into Bound Brook. Additionally, the groundwater elevations measured across OU3 by Foster Wheeler were approximately five feet lower than those observed in the recent data. The Foster Wheeler data were collected under historical pumping conditions related to operation of the Middlesex Water Company's Spring Lake wellfield, which ceased pumping operations in 2003. The groundwater withdrawals from the Spring Lake wellfield in this area likely caused a depression in local and regional groundwater elevations, which also created an intermittent groundwater gradient toward the Spring Lake wells, and reversed the local discharge/recharge potential between groundwater and surface water (Bound Brook). Since the cessation of pumping at Spring Lake, hydrogeologic conditions at the former CDE facility are influenced by the on-going groundwater withdrawals at the more distant Park Avenue wellfield.

1.6.4.4. Aquifer Recharge

As discussed above, during past pumping to the northeast of the former CDE facility at the Spring Lake wells, Bound Brook was potentially contributing to local recharge of the aquifer (FWENC, 2002). However, current groundwater data show that shallow groundwater is potentially discharging to Bound Brook, Cedar Brook, and Spring Lake and no longer received potential recharge from these sources. Based on the recent groundwater data, primary recharge to the aquifer is likely infiltration of precipitation through vertical fractures in bedrock.

1.6.5. Hydrology

Bound Brook is directly adjacent to the former CDE facility and forms the northeast border of the property. Bound Brook Corridor, the portion of Bound Brook adjacent to and downstream of the former CDE facility, extends from east to west through Edison, South Plainfield, New Market, Dunellen, and Middlesex. The low topography of Bound Brook Corridor has created the watershed features, hydrology, and drainage characteristics found in the region.

Prior to the OU2 remedial activities, the developed portion of the former CDE facility contained a network of catch basins to channel storm water runoff. Based on dye testing during the Foster Wheeler RI, it was believed that at least a portion of the catch basin network drained into two outfalls along Bound Brook (FWENC, 2002). The catch basin network was maintained during the OU2 remedial action, and at the conclusion of the OU2 soil remedial activities, an expanded catch basin network will collect storm water from the OU2 asphalt cap and will ultimately discharge to Bound Brook via a stormwater detention basin.

Spring Lake, an impoundment of Cedar Brook, lies within the Bound Brook Corridor and is located upstream from the former CDE facility. The Cedar Brook is the largest of the

Bound Brook tributaries and drains approximately 6.5 square miles. The impoundment at the western end of Spring Lake is man-made, formed by constructed dams and spillways, and controls the discharge flow of Cedar Brook into Bound Brook. Spring Lake supports secondary contact recreation including boating and fishing.

1.6.6. Ecology

1.6.6.1. Wetlands

According to National Wetlands Inventory mapping for the region, there are three wetland systems on the property associated with Bound Brook and its floodplain. The types of wetlands include: Palustrine Forested Broad-Leaved Deciduous Temporary (PFO1A), Palustrine Emergent Persistent Seasonal (PEM1C), and Palustrine Scrub/Shrub Broad-Leaved Deciduous Temporary (PSS1A). Wetland acreage ranges from 0.06 acres to 2.08 acres. A wetland delineation was completed in May 2007 to demarcate wetland/non-wetland boundaries as part of the remedial design for OU2. More information can be found in the Revised Final Habitat Assessment Report for Operable Unit 2 Soils (Malcolm Pirnie, 2008b).

1.6.6.2. Significant Habitat and Endangered Species

The developed nature of the Bound Brook Corridor restricts the availability of open space to uses supporting active recreational activities (i.e., recreational fields and mowed parkland), riparian habitat associated with flood prone or flood control wetland areas along Bound Brook and its tributaries, and the aquatic habitat associated with stream channels and man-made impoundments. While recreational fields and parkland afford open space, the pedestrian and vehicular traffic associated with these areas often is a limiting factor for more reclusive wildlife species. Likewise, avian and mammalian species that have adapted to the cosmopolitan nature of these areas can exploit the resources present. Species that exploit edge ecotones often are in numerically greater abundance than species favoring larger, contiguous parcels of woodland habitats. The developed nature of the landscape within the Bound Brook Corridor makes the forested and emergent wetlands and undeveloped upland habitats associated with the Bound Brook floodplain more critical as habitat refugia for wildlife species found in the corridor.

Areas where riparian tree canopies have been removed for development will contribute to greater light penetration and elevated water temperatures in the summer months. Runoff from the developed areas of the Bound Brook watershed has contributed non-point source pollutants such as sediments and contaminants associated with road runoff to favor more pollution-tolerant species of fish and invertebrates. Fishery surveys conducted by NJDEP and USEPA have identified the fishery as being a centrarchid (sunfish and basses)/cyprinid (minnows)/catostomid (suckers) dominated community. A single migratory fish species, the American eel, *Anguilla rostrata*, has been documented from the Bound Brook Corridor. Site reconnaissance data of the Bound Brook also identified the Asian clam, *Corbicula fluminea*, an invasive clam species, as being numerically

abundant in finer grained sediments present in the brook. Currently, the NJDEP classifies the Bound Brook reach within the Bound Brook Corridor as FW-2 non-trout waters. The designated uses for this classification include primary and secondary contact recreation and the protection, maintenance and propagation of warm water aquatic life. In addition to this FW-2 classification, the New Jersey 2004 Integrated Water Quality Monitoring and Assessment Report includes Bound Brook under Sublist 5, the lowest designated listing. A description of Sublist 5 as per USEPA guidance states: "The water quality standard is not attained. The waterway is impaired or threatened for one or more designated uses by a pollutant(s), and requires a total maximum daily load." The impairment criteria listed for Bound Brook under Sublist 5 include dioxin and PCBs as a result of NJDEP fish tissue monitoring.

1.6.7. Demography and Land Use

South Plainfield is located at 40°34'51"N, 74°24'50"W and is bordered by Piscataway on the south and west, Edison on the east, and Plainfield on the north. The former CDE facility is currently zoned for commercial/industrial use. As shown on Figure 1-12, land uses surrounding the former CDE facility are primarily commercial/light industrial to the northeast and east, residential to the south and north, and mixed residential/commercial to the west. The area within 1.5 miles of the former CDE facility contains eight schools and five parks. Two elementary schools are located approximately 2,000 feet from the former CDE facility (one to the north and the other to the south).

According to the 2006 Census, South Plainfield has an estimated population of approximately 22,795 people with a total land area of approximately 8.4 square miles (city-data.com), of which 8.36 square miles (99.52%) is land and 0.04 square miles (0.48%) is water. South Plainfield's population includes Caucasian (78%), African American (9%), Asian (8%), and Hispanic and other racial and ethnic groups (5%).

2. Remedial Investigation Findings

2.1. OU3 Remedial Investigation Approach

As discussed in Section 1, the Site is underlain by interbedded siltstone and mudstone of the Passaic Formation, which is part of the Newark Super Group. This geologic formation presents unique challenges to characterizing the nature and extent of groundwater contamination. One of the most notable challenges is characterizing the mass of contaminant sorbed or diffused into the matrix (i.e., primary porosity) of the bedrock, and the role it plays in the mass transport of contaminants. A new paradigm used for this type of bedrock hydrogeologic investigation is termed the Discrete Fracture Network (DFN) approach (Parker, 2007). The DFN approach, illustrated on Figure 2-1, is the foundation for the OU3 RI, and the basis for selection of appropriate remedial alternatives for evaluation in this FS.

2.1.1. Occurrence and Movement of Groundwater in Fractured Sedimentary Rock

Fractured sedimentary rock can be very difficult to characterize as it is highly heterogeneous and often anisotropic. The nature of the hydrogeologic system is dependent on a variety of factors, including rock matrix porosity and permeability, as well as fracture orientation, density and size.

Groundwater in fractured sedimentary rock occurs in the pore spaces or matrix of the rock (primary porosity), and in fractures of the rock (secondary porosity). This type of bedrock can be described as a “dual porosity” hydrogeologic system, where the pore spaces or rock matrix have a relatively high porosity, typically between 5% and 20%, and the fractures have a relatively low porosity, typically between 0.1% and 0.001%. The degree of interconnectedness of the pore spaces, termed effective porosity, will control the degree to which groundwater can move through the pore spaces or rock matrix. Similarly, the degree of interconnectedness of the individual fractures, termed secondary permeability, will control the degree to which groundwater can move through the fracture network.

The bulk of groundwater movement generally takes place in fractures, and the rate of groundwater movement in fractures is generally relatively high due to the high relative permeability of the fractures. The fractures also have a relatively low groundwater storage volume as compared to the rock matrix. Conversely, relatively little groundwater moves through the rock matrix because the rate of groundwater movement through the interconnected pore spaces of the rock matrix is generally very low. However, because the rock matrix has a relatively high porosity as compared to the fracture network, the rock matrix has a very high capacity for groundwater storage.

2.1.2. DNAPL Contamination in Fractured Sedimentary Rock

Dense non-aqueous phase liquids (DNAPLs) are among the most persistent contaminants in groundwater. When released into the environment, a DNAPL will flow downward through the unsaturated zone. The DNAPL will also flow downward through saturated porous media because it's denser than water. However, DNAPLs are non-wetting fluids and they have a very high surface tension, both of which affect the flow properties of the fluid and can lead to pooling.

Upon reaching the top of fractured sedimentary rock, the DNAPL will pool in areas of low permeability and they will continue to migrate downward through the highly transmissive fracture zones. The typically very low fracture porosity allows the DNAPL to migrate laterally and vertically great distances, far more than it would migrate in an equal volume of a porous medium (Feenstra and Cherry, 1988). DNAPL typically penetrates the fracture network, working into ever smaller openings, creating pools, fingers and disconnected globules of residual contamination. With time, the DNAPL will dissolve into groundwater and move as aqueous mass, which is then subject to dispersion, diffusion, sorption, and degradation (abiotic and biotic) processes (Figure 2-2).

Several groundwater studies have been conducted to understand the dynamic equilibrium between the advective fracture flow of aqueous contaminant mass and the diffusion of aqueous contaminant mass into the low permeability matrix. These studies show that the diffusion process is driven by the concentration gradient between the aqueous contaminant mass in the fracture and the matrix pore water.

In the early stages of aqueous contaminant mass movement in fractures, diffusion into the matrix (as well as other attenuation processes) can slow the advance of the aqueous contaminant mass in the fractures. In this stage, the aqueous contaminant mass does not move as quickly as groundwater that can be characterized by advective flow velocities because diffusion, sorption, and degradation are attenuating the leading edge of the aqueous contaminant mass. The aqueous contaminant mass is dispersed in the fracture network, which provides a large total surface area for attenuation processes. Early in the matrix diffusion process, most of the diffused mass occurs as 'halos' around discrete fractures indicating that the mass has penetrated only a short distance into the bedrock. (Parker et al., 1994).

As the plume matures, the rock matrix and aqueous fracture concentrations approach equilibrium. In addition, the advance of the aqueous contaminant mass in fractures slows and even potentially stops as the aqueous contaminant mass concentration gradients in the fractures and matrix reach a dynamic equilibrium. Dynamic equilibrium is generally achieved after a significant time period (~50 years). In cases with very large initial DNAPL releases (as evidenced at OU3), the high aqueous contaminant mass concentrations can drive the matrix diffusion process beyond the contaminant halo, to where the aqueous contaminant mass penetrates more than a few millimeters and totally saturates the matrix block.. This effect more commonly occurs in source areas, where

aqueous contaminant mass concentrations are highest and the residence time is the longest.

After a significant period (50 years) of time in the fractured bedrock environment, contaminant mass (i.e., DNAPL and or high concentrations of dissolved-phase mass) has been driven into the rock matrix by diffusion and aqueous-phase mass has been transported down gradient from the source area. The aqueous-phase mass concentrations in the fractures will be lower than the mass concentrations driven into the rock matrix. At this point, the process of matrix diffusion will reverse (back diffusion) releasing the mass in the rock matrix (pore water) back to the aqueous-phase in the fractures over a very long period of time (usually in multi-decade-to-multi-century timeframes). In addition, the distal portions of aqueous-phase mass will be stabilized because of attenuating processes (diffusion-driven mass transfer into the matrix, sorption, and biotic and abiotic degradation) that can significantly slow or stop the advance of the leading edge of the contaminant mass. However, as a result of on-going back diffusion, these types of impacted aquifers cannot be restored to their highest beneficial use (potable water supply) in a reasonable timeframe and at a reasonable cost.

2.2. Nature and Extent of Contamination

In accordance with the DFN approach, bedrock cores were sampled to characterize the extent of rock matrix contamination, and estimated pore water concentrations were calculated using the rock matrix data combined with physical rock characterization information. As discussed in Section 1, USEPA ERT conducted a limited bedrock groundwater investigation in August 2008 as a preliminary step to the OU3 RI. Groundwater samples were collected by Malcolm Pirnie in October 2009, March 2010, July 2010 (only PCBs and dioxins were analyzed), December 2010 (only MW-23 was sampled), and March 2011 (only MW-23 was sampled). Figure 2-3 shows the locations of the RI groundwater monitoring network. Table 2-1 lists the depth intervals that are monitored at each well location, as well as observations recorded by field geologists and used as rationale to locate sampling ports.

The October 2009 and March 2010 sampling events were comprehensive, in that all of the monitoring wells of interest were sampled, and a full suite of analyses was performed. Therefore, the data from these sampling events were used to identify contaminants of concern (COCs) in groundwater (see Table 2-2). The COCs may be categorized into the following classes of chemical compounds:

- VOCs, particularly chlorinated ethenes
- PCBs
- Inorganics
- PCBs -like Dioxins and Furans
- Pesticides

■ SVOCs

VOCs were the primary COCs used to define the extent of contamination due to their relative mobility in groundwater. In addition, because of the magnitude of the historical VOC groundwater concentrations at the former CDE facility, it was anticipated that their extent would be greater than or equal to the other COCs.

The OU3 RI report provides a detailed discussion of the nature and extent of these COCs (LBG and Malcolm Pirnie, 2011b). Tables summarizing all of the laboratory analytical data and field measurements are also provided in the OU3 RI report. Figures summarizing the RI data are provided herein as follows:

- Figure 2-4: Pore Water and Rock Matrix Trichloroethene Concentrations
- Figure 2-5: Pore Water and Rock Matrix cis-1,2-Dichloroethene Concentrations
- Figure 2-6: Trichloroethene in Groundwater 2009-2011 Sampling Events
- Figure 2-7: cis-1,2-Dichloroethene in Groundwater 2009-2011 Sampling Events
- Figure 2-8: CVOC Molar Mass Distribution in Shallow Water Bearing Zone (March 2010)
- Figure 2-9: CVOC Molar Mass Distribution in Intermediate Water Bearing Zone (March 2010)
- Figure 2-10: CVOC Molar Mass Distribution in Deep Water Bearing Zone (March 2010)
- Figure 2-11: Total PCB Arochlors in Groundwater 2009-2010 Sampling Events
- Figure 2-12: Arsenic in Groundwater 2009-2010 Sampling Events
- Figure 2-13: Lead in Groundwater 2009-2010 Sampling Events
- Figure 2-14: Dioxin Toxicity Equivalents (TEQs) in Groundwater July 2010 Sampling Event
- Figure 2-15: 4'-4-DDT in Groundwater 2009-2010 Sampling Events

The discussion below summarizes the RI conclusions regarding the nature and extent of contamination for all of the COCs with the exception of SVOCs. As shown in Table 2-2, relatively low concentrations of certain SVOCs, specifically polycyclic aromatic hydrocarbons (PAHs), were detected at disparate locations across OU3. These compounds are combustion by-products and are generally ubiquitous in urban/industrial environments.

2.2.1. Volatile Organic Compounds

Chlorinated ethenes comprise the great majority of contaminant mass of VOCs at OU3; therefore, this discussion will focus primarily on the nature and extent of chlorinated ethenes at OU3. Chlorinated ethenes are present at OU3 as non-aqueous phase liquid

(NAPL), they are sorbed or diffused into the rock matrix, and they are present as dissolved constituents in the fracture groundwater.

2.2.1.1. Chlorinated Ethenes Present as NAPL

Following borehole drilling and prior to final FLUTE™ well construction, NAPL reactive liners were installed in MW-14D, MW-15S, MW-15D, and MW-17 to test for the presence of NAPL. Only the reactive liner in MW-14D indicated the presence of NAPL. Based on a visual inspection of the liner, the depth at which the NAPL entered the borehole appeared to be relatively shallow, near the top of the open interval. The NAPL was evidenced by small globules that appeared on the liner at the interval below the bottom of casing (70 ft bgs), most likely moving along steep fractures that were intersected by the borehole. The liner exhibited evidence that the NAPL globules migrated down the lined borehole, and evidence of NAPL pooling at the bottom of the borehole was observed. The reactive liners in MW-15S, MW-15D, and MW-17 did not indicate the presence of NAPL.

The results of the RI suggest that the NAPL observed in MW-14D was the result of drilling through overburden materials that contained NAPL, and that significant quantities of NAPL likely are not present in the bedrock fractures. Complete DNAPL disappearance is supported by rock core data collected from the suspected source area showing all estimated porewater TCE concentrations less than the aqueous solubility limit (~1100 mg/L; from Pankow and Cherry, 1996), with a maximum TCE concentration of about 150 mg/L at 33 ft bgs (~13% of solubility). Similarly, groundwater concentrations in the FLUTE multilevel well at this location were much less than solubility, with a maximum TCE concentration of 72 mg/L in the shallowest port (30-35 ft bgs). Based on the strong concentration declines with depth at MW-14 both in the rock core data and FLUTE multilevel well groundwater data, it appears DNAPL penetration into bedrock may have been limited to the upper bedrock zone (i.e. upper 40 ft or less of bedrock). This limited penetration may have been controlled both by high horizontal fracture frequency and also by limited DNAPL release volumes. The RI report provides more information on Site history and what is known about historical releases at the Site. OU2 remedial activities at the Site have focused on removal of contaminated overburden to top of bedrock in the MW-14 area, as discussed more in the RI report.

2.2.1.2. Chlorinated Ethenes in Rock Matrix

Rock matrix samples were collected from MW-14S, MW-14D, MW-16, and MW-20 using methods described in the OU3 RI report. A total of 465 split rock core samples were collected for analysis of select VOCs from a combined total of 824 linear feet of rock core. Sample locations were determined based on fracture distribution, with a minimum sample frequency of one sample for every two feet of core. The rock matrix data are reported as mass of contaminant per mass of rock, and also as equivalent matrix pore water concentrations. Equivalent matrix pore water concentrations are calculated using estimated and directly measured physical properties of the rock, including wet rock

bulk density, dry rock bulk density, matrix porosity, soil-water partitioning coefficients, and organic carbon partitioning coefficients.

The concentrations of select VOCs (TCE and cis-1,2-dichloroethene (cDCE)) detected in rock matrix screening samples from the four borings are shown on Figures 2-4 and 2-5. TCE was the most common VOC present in the rock matrix samples (345 detections), followed by cDCE (96 detections), and PCE (27 detections).

COCs were detected in approximately 70% of the rock matrix samples collected in the center of the former CDE facility from two borings (MW-14S and MW-14D). The largest proportion of VOC mass was detected from 23 to 75 feet bgs (Shallow zone). The distribution of the results between 23 and 67 feet bgs indicates that contaminant mass has completely saturated the matrix blocks between fractures, indicative of very high aqueous concentrations, a dense fracture network, and sufficient time for VOCs to diffuse into the matrix. The observed matrix block saturation and concentrations are consistent with source area conditions identified in the DFN model of DNAPL behavior in fractured rock. A large fracture identified at approximately 67 feet bgs marked a steep decline in the overall rock matrix concentrations, and also marked a change in the distribution of mass. Below the fracture at 67 feet bgs, matrix block saturation decreases, and contaminant mass “halos” can be seen at 76, 82, and 89 feet bgs as evidenced by the stochastic distribution (concentration spikes) in rock matrix concentration.

COCs were detected in approximately 90% of the samples collected downgradient of the source area from one boring (MW-16), near the northern edge of OU3. The results indicate that VOC mass was detected throughout the entire cored interval. The largest proportion of VOC mass was detected in the 50 to 150 feet bgs depth interval (Intermediate zone). The distribution of the results between 50 and 150 feet bgs indicate that contaminant mass has partially saturated matrix blocks between fractures, and that there are zones (at approximately 60, 90, and 120 feet bgs) where the rock matrix concentrations are significantly lower than the surrounding blocks. The distribution of results suggests incomplete matrix saturation, which is more common with increased distance from the source area. Between 150 and 200 feet bgs, the rock matrix concentrations decrease steadily, and the stochastic distribution of mass becomes more prominent. This suggests that contaminant mass is present in fewer fractures, and at decreasing concentrations. The stochastic distribution of results continues below 200 feet bgs, and the concentrations generally stabilize at relatively low levels.

COCs were detected in approximately 80% of the samples collected downgradient of the Site from one boring (MW-20), adjacent to Spring Lake. The results indicate that VOC mass was detected throughout the entire cored interval. The largest proportion of VOC mass was detected from 220 to 350 feet bgs depth interval (Deep zone). The stochastic distribution of results between 28 and 220 feet bgs indicate presence of contaminant mass “halos” around discrete fractures (at approximately 85, 135, and 155 feet bgs), and that

the concentrations in the rock matrix are relatively low. The results also indicate that matrix block saturation has occurred between 220 and 250 feet bgs and between 255 and 355 feet bgs. The concentrations in these zones are relatively low as compared to those encountered in MW-14 and MW-16, but the consistent elevated results are indicative of matrix block saturation. These zones likely represent dense fracture zones that are in direct or indirect communication with contaminated groundwater. The stochastic distribution of results continues below 355 feet bgs, and the concentrations generally stabilize at relatively low levels.

2.2.1.3. Chlorinated Ethenes in Groundwater

USEPA ERT collected groundwater samples for VOC analyses in August 2008 as part of a pre-RI investigation. During the OU3 RI, groundwater samples were collected and analyzed for VOCs during two synoptic sampling rounds (October 2009 and March 2010). Groundwater samples were collected from shallow bedrock wells at the former CDE facility and from FLUTETM wells across OU3 with sampling ports that range in depth from 17 feet to 555 feet bgs (see Table 2-1 and Figure 2-3). In addition, one FLUTETM well (MW-23) was installed late in the program and its nine ports were sampled twice (December 2010 and March 2011). The groundwater VOC results were generally consistent across the three events (August 2008, October 2009, and March 2010). The distribution of TCE and cDCE in groundwater is shown on Figures 2-6 and 2-7. The following discussion details the distribution of VOCs for each hydrostratigraphic unit.

Shallow Groundwater

The highest concentration of VOCs was detected near the center of the former CDE facility, at depths between 23 and 75 feet bgs, with concentrations falling off sharply at depths greater than 75 feet bgs. Based on the concentrations of VOCs detected, the suspected source area is generally located at the center of the former CDE facility, near MW-11 and MW-14S and MW-14D. VOCs in the shallow bedrock are migrating to the northwest, consistent with both the observed shallow groundwater gradient, and the historical gradient reported in previous shallow bedrock investigations. The shallow water bearing zone impacts are generally limited to the area south of Bound Brook, as the surface water body acts as a boundary to shallow groundwater movement. However, elevated concentrations of VOCs in the shallow zone were detected north of Bound Brook in ERT-4, MW-20, and MW-21. Current vertical head distributions measured at several wells in OU3 show upward vertical gradients, indicating that the hydraulic potential exists for vertical mass transport. The elevated results at these locations suggest vertical mass transport along steeply dipping fractures.

The molar mass distribution of total ethenes (PCE, TCE, DCE, and VC) in the shallow zone, measured during the March 2010 event, is shown on Figure 2-8. The total CVOC molar mass distribution results show that cDCE is the primary organic constituent (by mass) at the suspected source area. However, the relative ratios of CVOCs vary greatly

across OU3. The high proportion of cDCE in the suspected source area suggests that reductive dechlorination of TCE is occurring.

Intermediate Groundwater

In the intermediate water bearing zone, the highest concentrations of CVOCs are found to the northwest of the suspected source area, at ERT-3. This indicates that the center of mass of the CVOC aqueous mass has moved to the north, generally consistent with the observed groundwater gradient. The distal portion of the aqueous contaminant mass is approximately one mile to the north and slightly east of the former CDE facility, which is generally consistent with the observed groundwater gradient. The current groundwater gradient would suggest a more northwesterly distribution of contaminants near the former CDE facility, with a northeastward arching path of travel into the capture zone of the currently operating Park Avenue wellfield to the north. This suggests that the historical groundwater gradient (due north to Spring Lake), which was responsible for driving advective mass transport during the early and intermediate stages of contaminant mass transport from the former CDE facility, is not consistent with the current groundwater gradient in the intermediate water bearing zone. The change in groundwater gradient is attributed to the historical pumping of four production wells located near Spring Lake. These wells, which are deep bedrock wells with open intervals to approximately 500 feet bgs, were seasonally operated by the Middlesex Water Company between 1964 and 2003. Additionally, the Tingley Lane wellfield likely added an additional northeastward component to the groundwater gradient. Historical pumping of these wellfields influenced the regional hydrogeologic setting and the groundwater gradient at the former CDE facility would have been highly variable: to the north or northeast when Spring Lake and Tingley Lane were active; to the northwest when only Park Avenue was active.

The molar mass distribution of total ethenes (PCE, TCE, DCE, and VC) in the intermediate zone, measured during the March 2010 event, is shown on Figure 2-9. The total chlorinated ethene molar mass distribution results show that cDCE is the primary organic constituent (by mass) at the suspected source area and along the axis of the aqueous contaminant mass, but that the TCE fraction is higher along the fringes of the delineated aqueous contaminant mass. The high proportion of cDCE in the suspected source area suggests that reductive dechlorination of TCE is occurring in the suspected source area and to a limited extent along the axis of the delineated aqueous contaminant mass. In addition, reductive dechlorination appears to be limited at the fringes of the delineated aqueous contaminant mass in the intermediate water bearing zone. As explained in the RI report, it is unlikely that contaminant mass from the former CDE facility impacted ERT-5 and ERT-6 (LBG and Malcolm Pirnie, 2011b).

Deep Groundwater

In the deep water bearing zone, the highest concentrations of CVOCs are found to the north of the suspected source area at the former CDE facility. This indicates that the center of mass of the CVOC aqueous mass has moved to the north, which is consistent

with the observed (north to northeasterly) groundwater gradient. As with the distribution of aqueous contaminant mass described in the intermediate water bearing zone, this suggests that the north/northeasterly historical groundwater gradient caused by pumping at the Spring Lake and Tingley Lane wellfields influenced advective mass transport during the early and intermediate stages of contaminant mass transport from the former CDE facility. The current groundwater gradient in the intermediate water bearing zone reflects the pumping influence of the more distant Park Avenue wellfield.

The molar mass distribution of chlorinated ethenes in the deep water bearing zone, measured during the March 2010 event, is shown on Figure 2-10. The total chlorinated CVOC molar mass distribution results show that cDCE is the primary organic constituent (by mass) at the suspected source area and along the axis of the aqueous contaminant mass, but that the TCE fraction is higher along the fringes of the delineated aqueous contaminant mass. The high proportion of cDCE along the axis of the delineated aqueous contaminant mass suggests that reductive dechlorination of TCE is occurring. In addition, reductive dechlorination appears to be limited at the fringes of the delineated aqueous contaminant mass in the deep zone. As explained in the RI report, it is unlikely that contaminant mass from the former CDE facility impacted MW-18 (LBG and Malcolm Pirnie, 2011b).

2.2.2. Polychlorinated Biphenyls (PCBs)

2.2.2.1. PCBs in Rock Matrix

PCB Aroclor analyses were performed for 212 rock matrix samples collected from three boring locations (MW-14S, MW-14D, and MW-16) during the OU3 Groundwater RI. Tables listing all of the results are provided in the OU3 RI report.

At MW-14S and MW-14D, the equivalent pore water concentration of PCB Aroclor 1254 in the rock matrix ranged from less than 0.31 ug/L at depths of 74 to 231.5 feet bgs to 1,800 ug/L at 61.55 feet bgs. The equivalent pore water concentration of PCB Aroclor 1248 in the rock matrix ranged from less than 1.4 ug/L at depths of 74 to 231.5 feet bgs to 3,500 ug/L at 61.55 feet bgs. In addition, one detection was reported from the boring at MW-16, where Aroclor 1254 was detected at 0.32 ug/L, which is the reported detection limit.

The results indicate that all of the detected PCB Aroclor mass was found in the 23 to 100 feet bgs depth interval in the source area (MW-14S and MW-14D). The largest proportion of PCB Aroclor mass detected was found in the 23 to 75 feet bgs depth interval. The stochastic distribution of PCB results indicate that diffusion of PCBs into the rock matrix is limited.

2.2.2.2. PCBs in Groundwater

Groundwater samples were analyzed for PCB Aroclors by the USEPA ERT in August 2008, and by Malcolm Pirnie during two synoptic OU3 RI sampling rounds (October 2009 and March 2010). In addition, one FLUTETM well (MW-23) was installed in

December 2010, and two rounds of samples were collected and analyzed for PCB Aroclors (December 2010 and March 2011). Tables listing all of the results are provided in the OU3 RI report.

The highest concentrations of PCB Aroclors were detected near the center of the former CDE facility, and nearly all of the exceedances were limited to shallow bedrock (Figure 2-11). The August 2008 event had PCB Total Aroclor exceedances in seven samples, with the highest concentrations of PCB Total Aroclors found in MW-12 (152J ug/L). All of the samples that exceeded the potential clean-up standard of 0.5 ug/L were located at the former CDE facility (MW-2A, MW-3, MW-5, MW-6, MW-8, MW-10, and MW-12). The October 2009 event showed a similar distribution of detections, with the highest concentrations of PCB Total Aroclors found in MW-14S (12,900 ug/L) at a depth of 65 feet to 70 feet bgs. All of the samples that exceeded the potential clean-up standard of 0.5 ug/L were located at the former CDE facility, with the exception of ERT-2 (5.1J ug/L), MW-19 (4.7J ug/L), and MW-20 (2.7J ug/L). Results from the March 2010 event were consistent with previous results, with the highest concentrations of PCB Total Aroclors found in MW-11 (190J ug/L), and all of the samples that exceeded the potential clean-up standard of 0.5 ug/L were located at the former CDE facility (Figure 2-11).

PCB Total Aroclor concentrations at the former CDE facility are generally highest at depths between 23 and 75 feet bgs, with concentrations falling off to non-detect at depths greater than 100 feet bgs. The horizontal distribution of PCB Total Aroclors is generally limited to the former CDE facility, with few exceptions detected during the October 2009 sampling event. Mobility of PCBs is limited by their low solubility and their affinity to sorb to organic matter in the soil and bedrock.

The concentration seen in one sample from MW-14S-04 during the October 2009 sampling event exceeded the aqueous solubility limit for PCB Aroclors. This indicates that the October 2009 groundwater results at MW-14 are impacted by the presence of NAPLs.

2.2.3. Inorganics

Aluminum, sodium, manganese, and iron were detected across OU3 at concentrations that exceed their respective potential cleanup standards. The highest concentration of aluminum was found in October 2009, at MW-17 (6200 ug/L) between 235 feet and 245 feet bgs. The highest concentration of sodium was found in March 2010 at MW-20 (691,000 ug/L) between 25 and 35 feet bgs. The highest concentration of manganese was found in March 2010, at MW-21 (2020 ug/L) between 505 feet and 515 feet bgs. The highest concentration of iron was found in October 2009, at MW-10 (8520 ug/L) between 37 feet and 52 feet bgs. These metals are regulated as secondary taste and quality (i.e., nuisance) contaminants and are generally considered to be naturally occurring.

There were no cadmium exceedances in the August 2008 sampling event; however, there was one cadmium exceedance in the October 2009 event at ERT-2 (4.6 ug/L) between

113 feet and 123 feet bgs, and one cadmium exceedance in the March 2010 event at MW-4 (16.8 ug/L) between 29 feet and 49 feet bgs.

Chromium exceeded its potential cleanup standard in only one well (MW-5) in all three sampling events. In the August 2008 event the concentration was 1180 ug/L between 12 feet and 28 feet bgs. In the October 2009 event the concentration was 77.9J ug/L, and in the March 2010 event it was 96.8 ug/L.

Barium exceeded its potential cleanup standard in only two wells (MW-11 and ERT-2) in all three sampling events. There were three barium exceedances in the August 2008 event at MW-11 (2380 ug/L) between 34 feet and 59 feet bgs, ERT-2 (6950 ug/L) between 25 feet and 35 feet bgs, and ERT-2 (2060 ug/L) between 40 feet and 50 feet bgs. There were two barium exceedances in the October 2009 event at MW-11 (2610J ug/L) between 34 feet and 59 feet bgs and ERT-2 (8790 ug/L) between 25 feet and 35 feet bgs. Lastly, there were two barium exceedances in the October 2009 event at MW-11 (2650 ug/L) between 34 feet and 59 feet bgs and ERT-2 (8330 ug/L) between 25 feet and 35 feet bgs.

The occurrence of aluminum and cadmium is sporadic, and is not consistent with the distribution of more soluble contaminants (i.e., CVOCs) historically associated with the former CDE facility. Chromium exceedances were found in only one location (MW-5), and barium exceedances were limited to just two locations (MW-11 and ERT-2). While there are few chromium and barium exceedances, they are limited to shallow bedrock, and their occurrence is generally consistent with a historic point source or release.

Arsenic was detected at concentrations that exceed the potential cleanup criteria in a majority of the samples collected in each of the three events (Figure 2-12). The highest concentration of arsenic was measured in the October 2009 event at MW-22 (595J ug/L) between 305 feet and 315 feet bgs. Although arsenic is present at concentrations above the potential cleanup standards, the occurrence is widespread and does not suggest a point source or release. The concentrations are generally consistent with naturally occurring concentrations measured in domestic water supply wells in the Newark Basin (New Jersey Geological Survey, 2004).

Lead exceeded the potential cleanup standard in five samples from five locations (ERT-2, ERT-4, ERT-5, MW-6, and MW-12) in the August 2008 sampling event, with the highest concentration found at MW-12 (5.9 ug/L). There were exceedances in 11 samples from five locations (ERT-7, FPW, MW-14S, MW-17, and MW-21) in the October 2009 event, with the highest concentration found at MW-21 (20.9 ug/L) between 50 feet and 60 feet bgs. There were exceedances in 14 samples from nine locations (ERT-7, FPW, MW-3, MW-6, MW-12, MW-13, MW-14S, MW-19, and MW-21) in the March 2010 event, with the highest concentration found at MW-12 (32.9 ug/L). The lead exceedances are distributed widely (Figure 2-13), but occur consistently at the former CDE facility. The exceedances at the source area (MW-14S, MW-12) are limited to shallow bedrock, and the occurrence of lead is generally consistent with a historical point source or release.

2.2.4. Dioxins

Following evaluation of PCB Aroclor data from the October 2009 sampling event, a subset of sampling locations was selected for analyses of PCB Congeners, Dioxins, and Furans. The sampling locations were selected based on their location (in order to obtain a representative distribution horizontally and vertically) and the concentrations of PCB Aroclors detected in October 2009. Twenty-four groundwater sampling locations were selected to be sampled twice (March 2010 and July 2010) for PCB Congeners, Dioxins, and Furans. Although there are no federal or state groundwater cleanup standards for individual PCB Congeners or Furans and only one standard for the individual dioxin compound, 2,3,7,8-Tetrachlorodibenzo(p)dioxin (2,3,7,8-TCDD), these data were used to calculate the Dioxin toxicity equivalent (TEQ) concentrations. Twelve dioxin-like PCB Congeners and 17 Dioxin/Furan congeners have been assigned a toxic equivalency factor relative to the most toxic dioxin, 2,3,7,8-TCDD, by the World Health Organization (Van den Berg, et al., 2006). Dioxin TEQ values were calculated for each of the 24 samples collected in March and July 2010. These values were then compared to the potential cleanup standard for 2,3,7,8-TCDD (10 picograms per liter (pg/L)).

The Dioxin TEQ exceeded the potential cleanup standard in six of the 24 sample locations (MW-1A, MW-3, MW-5, MW-11, MW-12, and MW-14S) in at least one of the two sampling events. The highest concentrations were detected in MW-14S (217,825 pg/L) between 65 feet and 70 feet bgs during both events (Figure 2-14). All six sampling locations that exceeded the potential cleanup standard are located within the boundaries of the former CDE facility.

The mobility of dioxins is limited by their low solubilities and their affinity to sorb to organic matter in the soil and bedrock. This is further evidenced by the sampling results, which show the extent of dioxin TEQ exceedances is limited to the former CDE facility. The concentration detected in one sample from MW-14S exceeds the general aqueous solubility limit for dioxin compounds. This indicates that the groundwater results at MW-14S may be influenced by the presence of NAPLs.

2.2.5. Pesticides

Pesticide compounds exceeded their respective potential cleanup standards in the August 2008 sampling event in 10 samples from nine locations (ERT-6, ERT-8, MW-01A, MW-02A, MW-3, MW-6, MW-7, MW-11, and MW-12), and the largest exceedance was the concentration of 4,4'-DDT found at MW-11 (14 JN ug/L). Results from the October 2009 event show there were pesticide exceedances in 22 samples from 13 locations (ERT-4, ERT-8, MW-02A, MW-4, MW-8, MW-9, MW-11, and MW-12, MW-14S, MW-14D, MW-15D, MW-16, MW-19, and MW-20), and the largest exceedance was the concentration of 4,4'-DDT found at MW-14S (4000J ug/L) between 65 feet and 70 feet bgs (Figure 2-15). During the March 2010 event, there were exceedances in nine samples from seven locations (ERT-8, MW-5, MW-6, MW-9, MW-11, MW-12, and MW-14S), and the largest exceedance was the concentration of dieldrin found at MW-14S (350JN ug/L) between 65 feet and 70 feet bgs.

Various pesticides, including 4,4'-DDT, dieldrin, chlorodane, and heptachlor were found at concentrations that exceed potential cleanup standards in samples collected from wells on and off the former CDE facility during each sampling event. The highest concentrations, and the largest exceedances of the potential cleanup standards, were encountered at the former CDE facility.

Mobility of pesticides is limited by their low solubility and their affinity to sorb to organic matter in the soil and bedrock. This is further evidenced by sampling results, which show the highest concentrations are limited to locations at the former CDE facility. The 4,4'-DDT concentration detected in one sample collected at MW-14S-04 (between 65 feet and 70 feet bgs) during the October 2009 sampling event exceeded its aqueous solubility limit. This indicates that the groundwater results at MW-14S may be influenced by the presence of NAPL.

2.3. Natural Attenuation Parameters

Natural attenuation processes, including biological degradation, typically influence the fate and transport of chlorinated ethenes in the subsurface. To aid in evaluating the potential for biological reductive dechlorination of chlorinated ethenes at OU3, groundwater samples from selected monitoring wells (ERT-1, MW-13, MW-14S/D, MW-16, MW-21, and MW-21) were analyzed for the following parameters that are used as indicators for biological degradation:

- Chloride
- Nitrate
- Sulfate;
- Ferrous iron
- Alkalinity;
- Total organic carbon
- Dissolved gases (methane, ethane, and ethene)

In addition, dissolved oxygen (DO) and oxidation/reduction potential (ORP) were measured in the field at every monitoring location. Tables listing the results from all of the analyses are provided in the OU3 RI report. Observations pertinent to this FS are discussed below.

Dissolved Oxygen

Chlorinated ethenes biodegrade most readily under anaerobic conditions via reductive dechlorination, which generally does not occur at DO concentrations greater than 0.5 milligrams per liter (mg/L). DO concentrations in groundwater samples collected during the RI ranged from 0.0 mg/L to more than 10 mg/L, with an average of 2.5 mg/L. DO concentrations in approximately 10 percent of the sampling locations exceeded 8.0 mg/L, which is the approximate solubility of oxygen in water at standard pressure and

temperature (Deutsch 1997). This is likely due to the FLUTe sampling method, which precluded the use of a flow-through cell or in-well DO probe.

In general, DO concentrations less than 0.5 mg/L were measured in samples from wells or ports at depths less than approximately 100 feet bgs during the first round of groundwater sampling in October 2009. However, during the second round of groundwater sampling in March/April 2010, DO concentrations less than 0.5 mg/L were measured in several samples collected at depths greater than 200 to 300 feet bgs.

Oxidation/Reduction Potential (ORP)

Reduction-oxidation (redox) reactions in groundwater containing chlorinated ethenes are typically biological and, therefore, the redox state of the groundwater influences, and is influenced by, the amount of biological degradation. Redox potentials less than (-) 100 millivolts (mV) are typically required to promote reductive chlorination; however, the reductive pathway is still possible at potentials less than (+) 50 mV (USEPA 1998).

Redox potentials measured in samples collected during the RI ranged from (-) 209 to (+) 337 with an average of (+) 101 mV. Redox potentials less than (+) 50 mV were generally only measured in samples collected from well/ports less than 100 feet bgs in the October 2009 sampling event. However, similar to the trends in DO concentrations, redox potentials less than (+) 50 mV were measured in many samples collected from depths greater than 200 feet bgs during the March/April 2010 sampling event.

Chloride

Elevated chloride concentrations in groundwater can be an indicator of reductive dechlorination; however, natural background chloride concentrations are often too high for this effect to be noticeable. The geometric mean of chloride concentrations in the samples was 40.5 mg/L. Chloride concentrations in samples collected from upgradient well ERT 1 ranged from 32.3 to 63.6 mg/L. Chloride concentrations in MW-14S/D ranged from 17.2 to 133 mg/L, with the highest concentrations measured in the top two sampling ports (Ports 1 and 2) (133 and 127 mg/L, respectively). Chloride concentrations in the samples collected from downgradient monitoring wells were similar to those measured at ERT 1, with the exception of the samples from monitoring well MW-20-1, which reached 1,670 mg/L.

Nitrate

Nitrate may be used as an electron acceptor for anaerobic biodegradation in the absence of oxygen. For reductive dechlorination to occur, nitrate concentrations in the groundwater must be less than 1.0 mg/L (USEPA 1998). Nitrate concentrations in the sampled wells/ports ranged from not detected (less than 0.11 mg/L) to 4.0 mg/L with a geometric mean of 1.11 mg/L. Nitrate was absent in monitoring wells MW-13 (ports 1 through 7), MW-14S (ports 1 through 4)/14D (port 1), MW-16 (ports 5 through 7), and MW-21 (ports 2, 3, 4, 5, and 7) in at least one of the groundwater monitoring events.

Sulfate

After dissolved oxygen and nitrate have been depleted, sulfate may also be used as an electron acceptor for anaerobic biodegradation in the absence of oxygen. For reductive dechlorination to occur, sulfate concentrations in the groundwater should generally be less than 20 mg/L (USEPA 1998). Sulfate concentrations in the sampled wells/ports ranged from 11.2 mg/L to 1,580 mg/L, with a geometric mean concentration of 54 mg/L. Sulfate concentrations less than 20 mg/L were detected in samples collected from monitoring wells MW-14S (ports 1,2, and 3) and MW-16 (ports 1 and 2).

Ferrous Iron

Under anaerobic conditions, ferric iron (Fe^{3+}) can be used as an electron acceptor during the biodegradation of petroleum compounds and, potentially, vinyl chloride. As result of this process, ferrous iron (Fe^{2+}), which is soluble in water, is produced and can be used as an indicator of biodegradation. Ferrous iron was not detected in any of the groundwater samples collected during the RI.

Alkalinity

Increased alkalinity can be an indicator of microbial activity in an aquifer. Alkalinity concentrations in groundwater samples collected during the RI ranged from 37.6 mg/L to 301 mg/L, with a geometric mean of 153 mg/L. Upgradient alkalinity concentrations in samples collected from monitoring well ERT-1 ranged from 184 mg/L to 210 mg/L. Alkalinity concentrations in source area monitoring well MW-14S/14D ranged from 175 to 301 mg/L. Downgradient alkalinity concentrations in monitoring well MW-20 ranged from 124 mg/L to 153 mg/L.

Organic Carbon

Organic carbon serves as both a carbon and energy source for microbes that drive reductive dechlorination. In general, total organic carbon (TOC) concentrations of greater than 20 mg/L are necessary to sustain biodegradational processes. TOC concentrations in groundwater samples collected during the RI ranged from 1.0 mg/L to 37 mg/L, with a geometric mean of 2.6 mg/L. TOC concentrations greater than 20 mg/L were detected in only one groundwater sample.

Dissolved Gases

Ethene and Ethane

Ethene and ethane are the final end-products of the complete reductive dechlorination of chlorinated VOCs. Therefore, their presence in groundwater is indicative of a complete dechlorination pathway. Ethene was detected in monitoring wells MW-14S/14D, MW-16, and MW-20 at concentrations ranging from 0.17 ug/L to 13.2 ug/L. Ethane was detected in monitoring wells MW-13, MW-14S/D, MW-16, and MW-20 at concentrations ranging from 0.14 ug/L to 5.8 ug/L.

Methane

The presence of methane in groundwater is indicative of strongly reducing conditions, and, therefore, is indicative of conditions favorable for reductive dechlorination (USEPA 1998). Methane was detected in 85 of the 97 (87 percent) groundwater geochemistry samples collected during the two groundwater sampling events. Methane concentrations in the samples ranged from 0.1 ug/L to 1,030 ug/L, with a geometric mean concentration of 8.9 ug/L.

Biological Natural Attenuation Evaluation

Reductive dechlorination is the most important process in the natural biodegradation of chlorinated solvents. For reductive dechlorination to completely degrade chlorinated VOCs, such as PCE and TCE, the geochemical conditions in the subsurface must be ideal and microorganisms that are capable of degrading the chlorinated VOCs must be present. Electron acceptors (chlorinated ethenes), electron donors (typically hydrogen or other fermentation products of organic carbon compounds), a reducing environment (ORP less than 50 mV), an anaerobic environment (DO less than 2.0 mg/L), depletion of competing electron acceptors (nitrate, ferrous iron, sulfate) and microbes (reductive dechlorinators) are all needed for reductive dechlorination to occur.

The USEPA Natural Attenuation Protocol Table 2.3 contains a screening process to evaluate the potential for reductive dechlorination based on Site monitoring data (USEPA, 1998). Using data from groundwater samples collected from monitoring well MW-14S/D (located in the presumed source area) resulted in a screening score of 16, which, according to the protocol, is indicative of adequate evidence for reductive dechlorination of the chlorinated VOCs present in the bedrock groundwater in the source area. These data included:

- The presence of the dissolved gases ethene and ethane, which are the final end products of the complete degradation of PCE and TCE.
- Low dissolved oxygen levels and reducing conditions demonstrated by low redox potentials and the presence of methane.
- Low nitrate (not detected) and sulfate (less than 20 mg/L) concentrations, which are indicative of the depletion of these potentially competing electron acceptors.
- The presence of TCE breakdown products cDCE and VC

However, based on the low organic carbon concentrations detected throughout the aquifer, the rate of reductive dechlorination is likely being limited by the lack of a carbon source. Additionally, the data also indicate the reductive dechlorination is more prevalent in the shallow groundwater than in the deeper portion of the aquifer where reducing conditions appear to be less prevalent.

2.4. Conclusions from BHHRA

A baseline human health risk assessment (BHHRA) (*Draft Baseline Human Health Risk Assessment, Operable Unit 3: Groundwater, Cornell-Dubilier Electronics Superfund Site, South Plainfield, New Jersey, June 2011* [LBG and Malcolm Pirnie, 2011a]) was conducted to support the RI/FS for OU3. The purpose of this BHHRA was to provide an

evaluation of potential human health risks, currently and in the future, in the absence of any major action to control or mitigate groundwater contamination (i.e., baseline risks). The potential for adverse health effects was expressed as incremental lifetime cancer risks and non-cancer hazards that were based on assumptions regarding the potential for human exposure to chemicals in groundwater, the estimated concentration of each chemical of potential concern (COPC) at the point of human contact, and the toxicity of each COPC.

The BHHRA followed guidance outlined in the USEPA Risk Assessment Guidance for Superfund: Volume I, Human Health Evaluation Manual (Part A) (RAGS) (USEPA, 1989) and other relevant USEPA guidance.

2.4.1. Data Evaluation

The BHHRA is based on the results of groundwater samples collected by Malcolm Pirnie, Inc. in October 2009, March-April 2010, July 2010, December 2010, and March 2011. Based on the conceptual understanding of Site-specific hydrogeology and to facilitate evaluation of the potential for human exposure to groundwater through the various pathways outlined in the Site Conceptual Exposure Model, the following groundwater exposure units were established for this BHHRA:

- **Entire aquifer** – includes groundwater data from all wells and across all sample depths. However, groundwater data from ERT-8 was not included because it is an upgradient well considered representative of background conditions.
- **Shallow onsite groundwater** – includes groundwater data from the shallow bedrock monitoring wells and the most shallow sampler port in each multi-port well located within the former CDE facility property boundary.
- **Shallow offsite groundwater, south of Bound Brook** – includes groundwater data from the most shallow sampler port in each of the multi-port wells located outside the former CDE facility property boundary and south of Bound Brook. Groundwater data from ERT-8 were not included because it is an upgradient well considered representative of background conditions.
- **Shallow offsite groundwater, north of Bound Brook** – includes groundwater data from the most shallow sampler port in each of the multi-port wells located outside the former CDE facility property boundary and north of Bound Brook.

COPCs were identified in each groundwater exposure unit, based primarily on comparison of the maximum concentration of each detected chemical to the USEPA Regional Screening Levels for tap water but including other selection criteria as well.

2.4.2. Exposure Assessment

Representative exposure point concentrations (EPC) to be used in the calculation of lifetime incremental cancer risks and non-cancer hazards were estimated for each COPC. Concentrations in groundwater and indoor air were calculated to evaluate human exposure through the potential pathways and exposure routes outlined in the Site Conceptual Exposure Model. This model describes the scenario timeframe, exposure

medium, exposure point, and the exposure pathways and routes by which human receptors may be exposed to COPCs originating in groundwater.

Based on the current and most likely future land uses of the Site, the following human receptor populations were identified: commercial/industrial workers, resident adults, resident children, and construction/utility workers. The potential for dermal contact and inhalation exposure to chemicals in groundwater used for process or industrial uses was evaluated for commercial/industrial workers. The potential for ingestion, dermal contact, and inhalation exposure to chemicals in groundwater used as a source of potable water was evaluated for resident adults and children. The potential for dermal contact and inhalation exposure to chemicals in groundwater that pools at the bottom of a trench excavated for utility work was evaluated for construction/utility workers. The applicable exposure unit for the commercial/industrial worker, resident adult and resident child exposure scenarios was the entire aquifer. Each of the three shallow groundwater exposure units was used in a separate evaluation of potential construction/utility worker exposure.

In accordance with USEPA guidance, estimates of reasonable maximum exposures (RME) and, where applicable, central tendency exposures (CTE) were generated. Use of RME parameter values simulates the highest exposure that might reasonably be expected to occur, one that is well above the average case but within the range of possibility, and results in upper-bound incremental lifetime cancer risks and non-cancer hazards. Evaluation of the RME scenario serves as the determination regarding remedial action.

2.4.3. Toxicity Assessment

Chemical-specific toxicity information is in the form of cancer potency slope factors or unit risk factors and non-cancer reference doses or reference concentrations. Toxicity values were obtained from the following hierarchy of sources: USEPA's Integrated Risk Information System, USEPA's Provisional Peer-Reviewed Toxicity Values, and additional sources, including but not limited to the California Environmental Protection Agency and the Agency for Toxic Substances and Disease Registry.

2.4.4. Risk Characterization

Individual (i.e., COPC-specific) incremental lifetime cancer risks and non-cancer hazard quotients were calculated for each potential human receptor population. For the construction/utility worker, separate risk estimates were generated for each of the three shallow groundwater data sets.

Individual incremental lifetime cancer risks are expressed as unitless probabilities (e.g., 2×10^{-6} or 2 in 1,000,000) of a person developing cancer. The individual cancer risks for each exposure scenario were summed to arrive at an estimate of the total cancer risk from exposure to multiple chemicals. For known or suspected carcinogens, the National Oil and Hazardous Substances Contingency Plan (NCP) established that acceptable exposure levels are generally concentration levels that represent an incremental upper-bound lifetime cancer risk in the range from 10^{-4} (i.e., 1×10^{-4} or 1 in 10,000) to 10^{-6} (i.e., 1×10^{-6}

or 1 in 1,000,000) or less. The cancer risks estimated for each exposure scenario were compared to this risk range established by the NCP.

Non-cancer hazard is expressed as the unitless ratio, termed the hazard quotient (HQ), of the daily chemical intake or exposure concentration to the non-cancer reference dose or reference concentration. For systemic toxicants, the NCP established that "acceptable exposure levels shall represent concentration levels to which the human population, including sensitive subgroups, may be exposed without adverse effect during a lifetime or part of a lifetime, incorporating an adequate margin of safety" (USEPA, 1990). As the non-cancer reference dose is protective of the potential for adverse, non-cancer health effects, HQs greater than $1E+00$ indicate the potential for non-cancer hazard. The total individual non-cancer HQs were summed for each exposure scenario to yield hazard indices (HI) that reflect the potential for adverse, non-cancer health effects from exposure to multiple chemicals.

The BHRAA found that the incremental lifetime cancer risks and non-cancer hazards for each RME scenario evaluated in the BHHRA for OU3. As shown, the incremental lifetime cancer risks range from $8E-07$ for the construction/utility worker exposure to shallow offsite groundwater, north of Bound Brook to $2E-02$ for the resident adult. Incremental lifetime cancer risks for the commercial/industrial worker, resident adult and resident child are greater than the cancer risk range established by the NCP. The predominant contributors to the cancer risk estimated for the resident adult are 4,4'-DDT, 4,4'-DDD, trichloroethylene, and arsenic.

Non-cancer HIs range from $3E+00$ for the construction/utility worker exposure to shallow offsite groundwater, north of Bound Brook to $8E+02$ for the resident child. The non-cancer HIs are greater than $1E+00$ for all potential human receptors, indicating there is the potential for adverse, non-cancer health effects from exposure to groundwater. The predominant contributors to the non-cancer hazard estimated for the resident child are cis-1,2-dichloroethene, total PCB Aroclors, and 4,4'-DDT.

For the CTE scenario, the BHRAA found that the incremental lifetime cancer risks range from $2E-07$ for the construction/utility worker exposure to shallow offsite groundwater, north of Bound Brook to $3E-03$ for the resident child. Incremental lifetime cancer risks for the commercial/industrial worker, resident adult and resident child are greater than the cancer risk range established by the NCP.

Non-cancer HIs range from $3E+00$ for the construction/utility worker exposure to shallow offsite groundwater, north of Bound Brook to $4E+02$ for the resident child. Again, the non-cancer HIs are greater than $1E+00$ for all potential human receptors, indicating there is the potential for adverse, non-cancer health effects from exposure to groundwater.

The RI Report established that aqueous contaminant mass from the former CDE facility has been interpreted to not extend to ERT-5 and ERT-6 in the intermediate zone, and MW-18 in the deep zone. Because of the uncertainty associated with modeling groundwater flow through fractured bedrock, groundwater data from ERT-5, ERT-6, and MW-18 were included in the entire aquifer and shallow offsite, south of Bound Brook data sets used to estimate baseline cancer risks and non-cancer hazards. However, to determine the relative contribution that groundwater data from these offsite wells make to the baseline cancer risks and non-cancer hazards estimated in this BHHRA, an uncertainty evaluation was conducted using only groundwater data from ERT-5, ERT-6, and MW-18. Based on this evaluation, it was concluded that a portion of the potential for cancer risk and non-cancer hazard indicated in the baseline evaluation may be attributed to concentrations of dibenzo(a,h)anthracene, total PCB Aroclors, and arsenic detected in ERT-5, ERT-6, and MW-18.

For the evaluation of the potential for adverse health effects from resident child exposure to lead in drinking water, the geometric mean blood lead level (PbB) concentration estimated using the Integrated Exposure Uptake Biokinetic model for lead in children is 2.6 µg/dL. The probability that the PbB concentration is greater than 10 µg/dL is 0.22 percent. Therefore, lead concentrations in groundwater should not pose a risk to resident children or, by extension, to resident adults.

2.5. Conceptual Site Model

Groundwater flow in the Passaic Formation occurs primarily through the fracture network. The network is composed of bedding parallel to sub-parallel fractures with steeply dipping joint sets and is highly conductive and interconnected, allowing for the horizontal and vertical movement of groundwater. The average fracture aperture size is 83 microns, or slightly smaller than the thickness of human hair. The extremely small size of the apertures, and an average fracture frequency of 0.9 fractures per every linear foot, gives the fracture network a relatively low porosity ($2.1 \times 10^{-5} \text{ ft}^3/\text{ft}^3$) as compared to the porosity of the matrix rock ($0.1 \text{ ft}^3/\text{ft}^3$). However, the fracture frequency, volume, and interconnectedness give the network a moderate bulk hydraulic conductivity (2.2 to 5.5 ft/day) and allows for both vertical and horizontal groundwater flow.

The aquifer is divided into three hydrogeologically connected units (for discussion purposes): the shallow, intermediate, and deep water bearing zones. The shallow water bearing zone is unconfined and extends from ground surface to a depth of approximately 120 feet bgs (unconsolidated materials and bedrock). The current phreatic surface in shallow bedrock (water levels recorded in the shallow bedrock aquifer) is above the top of bedrock, and within the unconsolidated deposits. The confined intermediate water bearing zone has experienced less in-filling of fractures by sediments, and is therefore more uniformly permeable. The deep water bearing zone is confined and has the most open and permeable fractures in the aquifer. The fracture network exerts an increasing control over groundwater movement, below about 250 feet bgs due to a decrease in aperture size and frequency of fractures.

Water levels measured during the RI indicate that the water table in the shallow water bearing zone is generally controlled by topography and elevation. Groundwater in the shallow water bearing zone may discharge to Bound Brook, Cedar Brook, and Spring Lake and moves north and east from the former CDE facility toward Bound Brook and northwest toward the low-lying area at the confluence of Bound Brook and Cedar Brook. Groundwater movement in both the intermediate and deep water bearing zones is dominated by the influences of pumping at the Park Avenue wellfield to the north of the former CDE facility.

The highly conductive fracture network allows for the vertical and horizontal advection of groundwater and aqueous contaminant mass. Because the fracture network is so pervasive, it provides a relatively large surface area for the VOCs to sorb onto and then diffuse into the rock matrix. The pore volume of the rock matrix is nearly two orders of magnitude larger than the fracture network, allowing it to hold the majority of the contaminant mass. Once the aqueous contaminant mass has diffused into the rock, it is left nearly immobile because of the low hydraulic conductivity of the rock matrix. However, there is a continual exchange of contaminant mass with passing groundwater driven by concentration gradients. In addition to sorption and diffusion, microbiological analyses indicate that the degradation of CVOCs is occurring, which contributes to the retardation of the advance rate of the leading edge of aqueous contaminant mass.

The aqueous contaminant mass migration has also been influenced by historical intermittent pumping at Spring Lake, which took place between 1964 and 2003, intermittent pumping at the Tingley Lane wellfield, and by ongoing withdrawals at the Park Avenue wellfield. Although the general direction of groundwater movement beneath the former CDE facility is to the north-northwest, the pumping centers to the north and east of the former CDE facility redirected the groundwater movement and mass transport. Today, groundwater extraction at the Park Avenue wellfield, along with potential groundwater discharges to Bound Brook and Spring Lake, are the dominant hydraulic influences on the regional and local hydrogeology.

A distinct, highly transmissive fracture zone was intersected by several boreholes during the investigation. This fracture zone likely facilitated the down gradient transport of aqueous contaminant mass along a preferential (high transmissivity) pathway. While pumping at Spring Lake was occurring, the downward vertical component of the groundwater gradient was higher, thereby increasing the downward movement of the contaminant mass. This fracture zone is capable of conducting the aqueous contaminant mass down gradient toward the Spring Lake pumping wells, and toward the Park Avenue wellfield.

When Spring Lake pumping ceased in 2003, the groundwater flow regime began to revert to a condition similar to the previous hydrogeologic regime dominated by the Park Avenue wellfield. Groundwater levels rose nearly five feet at the former CDE facility

(this water level rise may not be entirely due to cessation of pumping at Spring Lake, but could also have resulted from potential increased recharge), Bound Brook became a potential gaining stream, and groundwater movement near the former CDE facility shifted to the northwest, rather than north to Spring Lake. In addition, the flow field to the north of Bound Brook shifted to the northeast due to ongoing groundwater extraction at the Park Avenue wellfield. These changes in conditions likely resulted in advective redistribution of the aqueous contaminant mass. In areas where concentrations of aqueous contaminants in fractures are greater than those in the adjacent matrix pore water, contaminant diffusion into the rock occurs, attenuating advective distribution of the aqueous contaminant mass. Furthermore, back diffusion of contaminants out of the matrix (pore water) occurs in areas where the contaminant concentration gradient between the rock matrix and the aqueous phase in fractures supports the process, which may contribute to ongoing groundwater contamination over a very long period of time (usually in multi-decade-to-multi-century timeframes). As a result, the contaminated aquifer cannot be restored to its highest beneficial use (potable water supply) in a reasonable timeframe and at a reasonable cost.

2.6. Contaminant Transport Modeling

In support of the RI/FS process, contaminant (chlorinated VOC) fate and transport modeling was conducted to evaluate the extent of contaminant migration in the bedrock groundwater and the impact of potential source treatment remedies. The modeling was conducted and reviewed by Steven Chapman, Dr. Beth Parker, and Dr. John Cherry of the University of Guelph. The results of the modeling are presented in the *Draft Report on Discrete Fracture Network (DFN) Contaminant Transport Modeling, Cornell-Dubilier Electronics Superfund Site – OU3 Groundwater*, dated June 2011 (DFN Modeling Report) (Chapman 2011), which is included in Appendix A, and summarized herein.

Pumping tests at the CDE Site show that the groundwater flow system in the highly fractured bedrock can be reasonably simulated as an equivalent porous media (EPM). However, evaluation of contaminant fate and transport must consider effects of matrix diffusion on contaminant behavior in discretely fractured rock systems. While fractures provide the dominant pathways for groundwater flow, the large rock matrix porosity represents the bulk of the contaminant mass storage capacity. Thus diffusion of contaminants into the rock matrix in this dual porosity system, as well as sorption within the matrix and potentially contaminant degradation, is expected to have a strong influence on contaminant behavior and remedial efficacy.

2.6.1. Model Approach

The modeling approach applied at the CDE Site involved application of the MODFLOW EPM model to simulate the groundwater flow system to obtain overall bulk flow characteristics (i.e., hydraulic gradients, bulk hydraulic conductivity and groundwater fluxes) and then the discrete fracture network (DFN) model FRACTRAN was used to simulate contaminant fate and transport. The purpose of the DFN transport simulations is

to represent groundwater flow and contaminant transport in fractured porous media incorporating relevant processes of rapid groundwater flow in fractures and contaminant diffusion into and out of the rock matrix.

The FRACTRAN DFN simulations were conducted for TCE only assuming no degradation. Data from the Site suggest transformation of TCE to cis-DCE occurs, but it is unknown whether much further dechlorination occurs since groundwater data shows little VC presence. The model domain for the site simulations was a vertical cross-section 1000 meters (m) long and 150 m high. The fracture network was selected after producing several realizations of randomly generated fracture networks and adjusting the key fracture network statistics including mean fracture aperture and variance, fracture density, and fracture length ranges to provide an overall horizontal bulk hydraulic conductivity within a target range based on the field data (e.g., FLUTE liner test data and pump test data). The vertical head component was set to match the apparent plume deepening with depth based on the rock core VOC results. The 'source zone' was positioned within the upper portion of the model domain consistent with the apparently limited DNAPL penetration.

2.6.2. Model Results

The results of the FRACTRAN DFN transport simulations showed that contaminant migration in the fracture network is much slower than groundwater flow rates in fractures, due to attenuation processes including diffusion of mass from fractures to the rock matrix. However, the simulation results show that by 10 years contamination has already reached the model boundary at 1000 m, and by 50 years contamination occurs throughout the model domain. Overall the FRACTRAN transport simulation results confirm the strong attenuation inferred based on the field data, showing matrix diffusion effects can account for such strong plume attenuation when combined with a finite source input. Given that the majority of contaminant mass now occurs in the rock matrix, mass discharge in downgradient portions of the plume may be relatively small. For example, based on the FRACTRAN results the mass discharge in the downgradient portion of the plume at X=800 m at 50 years was assessed. This provides an estimated TCE mass discharge at 50 years of about 0.3 kg/year per m width (since model domain is a vertical cross-section with unit thickness). With expectations of strong attenuation with distance, mass discharge would be significantly lower than this further downgradient. Thus, even if the Park Avenue well field is a potential receptor of aqueous contaminant mass from the former CDE facility, any resulting increase in concentrations would likely be very small when dilution effects from pumping are factored in.

2.6.3. Future Projections

For future projections, two scenarios were assumed: (1) continued input at 10% of solubility, and (2) complete removal of the source input term. The latter scenario is consistent with the recent OU2 remedial efforts focused on contaminated overburden removal, assuming any remnant DNAPL in overburden is successfully removed and no longer contributes mass to the bedrock system. This could also represent a scenario where

not all DNAPL is removed, but where a source zone hydraulic control system is put in place where any contaminant mass emanating from the source zone is captured and treated. The results show little impact from complete removal of source mass input on persistence of the downgradient plume, which may be expected given that the majority of the contaminant mass exists in the rock matrix. While some minor improvements in groundwater quality internally within the plume are achieved from complete source removal or cutoff, the time to achieve such benefits are extremely long and concentrations still remain elevated for very long time periods (i.e., on the order of several hundred years).

Actual source conditions at the CDE Site are likely in between the two scenarios given recent efforts to remove contaminated overburden materials. While these FRACTRAN DFN simulations do not incorporate a sufficiently large domain to capture the full simulated plume extent, the expectation is that the rate of plume front migration would be very slow at present time due to effects of matrix diffusion. These simulations also suggest efforts to completely remove source inputs would have negligible impact on conditions nearer the plume front within any reasonable timeframe.

3. Remedial Action Objectives

RAOs are specific goals for protecting human health and the environment. The development of these goals involves consideration of ARARs and to be considered (TBC) materials, as well as the results of the BHHRA. An overview of ARARs and TBC information is presented, followed by identification of site-specific ARARs. PRGs are then selected that conform to the ARARs and TBCs. Then, GRAs are selected to satisfy the RAOs.

3.1. Overview of ARARs

3.1.1. Definition of ARARs

CERCLA 121(d)(2)(A) requires that remedial actions comply with or waive identified ARARs. ARARs consist of two sets of requirements: those that are applicable and those that are relevant and appropriate. Applicable requirements are those substantive standards that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a National Priorities List (NPL) site. The second set of requirements consists of relevant and appropriate requirements. The relevance and appropriateness of a requirement may be judged by comparing a number of factors, including the characteristics of the remedial action, the hazardous substances in question, or the physical characteristics of the site, with those addressed in the requirement. A requirement that is judged to be relevant and appropriate must be complied with to the same degree as if it were applicable.

3.1.2. "To Be Considered" Information

Many federal and state environmental and public health agencies develop criteria, advisories, guidance, and proposed standards that are not legally enforceable, but contain information that would be helpful in carrying out, or in determining the level of protectiveness of, selected remedies. TBC materials are meant to complement the use of ARARs, not compete with or replace them. Because TBCs are not ARARs, their identification and use are not mandatory.

Where no ARARs exist to address a particular situation, the TBCs may be used to set cleanup targets (in conjunction with a baseline risk assessment). Many ARARs have broad performance criteria but do not provide specific instructions for implementation. Often, these instructions are contained in supplemental program guidance that may be considered TBCs.

3.1.3. Types of ARARs

Any substantive environmental requirement has the potential to be an ARAR. A substantive requirement typically specifies a level or standard of control, although it could also provide performance criteria or location restrictions. To simplify the universe of such requirements, USEPA divides ARARs into three categories to facilitate identification:

- **Chemical-Specific ARARs**: are either health- or risk-based numerical values or methodologies that establish the acceptable amount or concentration of a chemical that may remain in or be discharged to the environment. Where more than one requirement addressing a contaminant is determined to be an ARAR, the most stringent requirement should be applied, unless it is waived by the Regional Administrator.
- **Location-Specific ARARs**: are restrictions of certain activities based on the concentration of hazardous substances solely because of geographical or land use concerns. Requirements addressing wetlands, historic places, floodplains, or sensitive ecosystems and habitats are potential location-specific ARARs.
- **Action-Specific ARARs**: set restrictions on the conduct of certain activities or operation of certain technologies at a particular site, and are primarily used to assess the feasibility of remedial technologies and alternatives. Regulations that dictate the design, construction, and operating characteristics of incinerators, air stripping units, or landfills are examples of action-specific ARARs.

3.2. Identification of Applicable or Relevant and Appropriate Requirements

3.2.1. Chemical-Specific ARARs and TBCs

Chemical-specific ARARs define concentration limits for environmental media. The bedrock aquifer at the Cornell-Dubilier Electronics Superfund Site has been identified by New Jersey as Class IIA (a potential source of drinking water). Therefore, ARARs include relevant standards derived from the Safe Drinking Water Act Maximum Contaminant Levels (MCLs) (40 CFR 141), the New Jersey Drinking Water Quality Act MCLs (New Jersey Administrative Code [NJAC] 7:10-16), and the New Jersey Groundwater Quality Criteria (NJAC 7:9-6). Chemical-specific ARARs are listed in Table 3-1. Groundwater TBC information includes USEPA risk-based regional screening levels. The numerical NJDEP Groundwater Quality Criteria, NJDEP MCLs, and Federal MCLs for the OU3 COCs are listed in Table 3-2.

3.2.2. Location-Specific ARARs and TBCs

3.2.2.1. Floodplains and Wetlands

The northeastern border of the former CDE facility property is the Bound Brook. Most of the property, including the formerly developed portion, lies outside of the flood hazard

area and the 100- and 500-year floodplains. The southeastern portion of the facility, however, is located within the flood hazard area and the 100- and 500-year floodplains of the Bound Brook (FWENC, 2002). Several wetland areas are also present adjacent to the Bound Brook and in the southwestern portion of the facility (Malcolm Pirnie, 2008b). The federal and state ARARs and TBC materials associated with protecting floodplains and wetlands during remedial activities are listed in Table 3-3.

3.2.2.2. Historical and Cultural Resources

A cultural resources Phase 1B investigation is currently underway as part of OU2 remedial activities. A cultural resources survey will be performed as part of the OU4 RI for areas within the Bound Brook floodplain. Additional surveys may be conducted prior to remedial activity to ensure that no historic resources will be affected by the activity, in accordance with ARARs listed in Table 3-3.

3.2.2.3. Rare, Threatened, or Endangered Species

No state or federal threatened or endangered species have been identified in the vicinity of the former CDE facility. However, as part of Natural Heritage Data Requests made in support of the *Revised Final Habitat Assessment Report for OU2* (Malcolm Pirnie, June 2008), the US Fish and Wildlife Service (USFWS) indicated that the Indiana bat has the potential to be in the area. Furthermore, the National Oceanic and Atmospheric Administration (NOAA), as part of a site review, identified the catadromous American eel as a trust resource in Bound Brook (NOAA, 1999). Additional inquiries have been made of NJDEP as part of the on-going OU4 RI. Table 3-3 lists ARARs specific to protection of threatened or endangered species in the event that they are identified in the future.

3.2.3. Action-Specific ARARs and TBCs

Most action-specific ARARs and TBC information address treatment, transportation, and disposal of hazardous waste. Table 3-4 includes descriptions of action-specific ARAR that may be associated with potential remedial actions. A detailed discussion of ARAR compliance for specific remedial alternatives is included in Section 6.

3.3. Technical Impracticability

Technical Impracticability (TI) is a regulatory determination that remedial actions at the Site, or a portion of the Site, cannot achieve remediation goals (e.g., chemical-specific ARARs) using available technologies due to several possible factors. These factors may include technology limitations, contaminant phase (i.e., aqueous versus NAPL), contaminant depth, complexity of geological setting, and hydraulic regime (e.g., low hydraulic conductivity). As a result, the owner/operator will not be required to meet the ARARs, but may be required to meet an alternative level or achieve an alternative remedial goal. Furthermore, a TI decision applies only to the spatial three-dimensional area (TI zone) in which ARARs or other cleanup standards will not be achieved. Outside of the TI zone, the ARARs will still remain as the final cleanup goal. Sites incorporating

TI waivers into final decision documents must maintain protection of human health and the environment.

As indicated in the USEPA document *Technical Impracticability Decisions for Ground Water at CERCLA Response Action and RCRA Corrective Action Sites* (USEPA, 1998), a NAPL release in fractured sedimentary bedrock is an example of site conditions that may pose technical limitations to aquifer restoration. At OU3, the RI demonstrated that a significant portion of the contaminant mass now resides in the low-permeability rock matrix where groundwater is nearly immobile; therefore, implementation of remedial technologies that are typically capable of removing mass from the fractures only is futile due to back diffusion.

While evaluating potential remedial technologies for this FS, the technical feasibility of aquifer restoration and the need to waive ARARs for TI was also evaluated. Based upon the findings of the potential for aquifer restoration, it has been concluded that a waiver of the groundwater ARARs is recommended due to TI. A stand-alone TI Evaluation Report (TIER) was prepared to document the need to waive ARARs. The TIER documents the specific ARARs being waived and the area where a TI waiver is needed.

Figure 3-1 shows the extent of the TI zone based on the assessment performed in the TIER. As discussed in the RI, based on the direction of groundwater flow from groundwater modeling and potentiometric surface maps, and the current understanding of the historical pumping of nearby wellfields, aqueous contaminant mass from the former CDE facility could not have impacted monitoring wells ERT-5, ERT-6, and MW-18. However, for monitorability purposes, these wells have been included in the TI zone.

[NOTE TO REVIEWER: A MORE SPECIFIC REFERENCE TO THE TIER WILL BE ADDED TO THIS SECTION AFTER USEPA COMPLETES REVIEW OF THIS DRAFT FS REPORT].

3.4. Remedial Action Objectives

In developing RAOs for groundwater, USEPA expects to return usable groundwater to its beneficial uses wherever practicable, within a timeframe that is reasonable given the characteristics of the site. USEPA also acknowledges, however, that groundwater restoration to drinking water standards is not always achievable due to limitations in remedial technologies and other site-specific factors.

The RI established that much of the contaminant mass initially released as a DNAPL into the bedrock fractures at OU3 currently resides as sorbed and dissolved mass in the mudstone rock matrix. Back-diffusion of the contaminants in the rock matrix are continuing sources for the bedrock groundwater. Given the difficulties of accessing or removing contaminant mass from the rock matrix, it is unlikely that application of any existing remedial technologies will result in the achievement of drinking water standards

within a reasonable time-frame. As discussed above, it is recommended that a waiver of the groundwater ARARs be required due to TI.

Wells used to supply groundwater for potable and non-potable uses are located within a 1-mile radius of the former CDE facility. When restoration of groundwater to beneficial uses is not practicable, USEPA expects to prevent further migration of contaminants, prevent exposure to the contaminated groundwater, and evaluate further risk reduction. The RAOs for OU3 have been developed to satisfy these expectations with respect to prevention of exposure to contaminated groundwater via direct contact, ingestion, or inhalation. The potential for groundwater constituents to migrate to surface water and sediments in Bound Brook is being evaluated as part of OU4. RAOs related to the surface water discharge pathway will be developed as part of the OU4 CERCLA process. The RAOs for OU3 are as follows:

- Prevent migration of contaminants to areas beyond the TI zone.
- Reduce the potential human health and ecological risks to receptors from exposure by contact, ingestion, or inhalation of contaminated groundwater.

3.5. Preliminary Remediation Goals

Preliminary remediation goals were developed for groundwater based on the ARARs discussed above. The most stringent of the federal MCLs, NJDEP MCLs, and NJDEP groundwater quality criteria were selected as the remediation goal for the COCs (see Table 3-2). Consistent with the RAOs and the TI waiver, these numerical goals will be used for developing use restrictions and other actions to prevent exposure, and for assessing the extent of the aqueous plume, but not for achieving restoration of groundwater to the numeric goals/criteria.

4. Evaluation and Screening of General Response Actions and Remedial Action Technologies

The purpose of this section is to identify and screen GRAs and remedial technologies and process options that can potentially achieve the RAOs identified in Section 3. The technology selection and screening processes were conducted in accordance with the USEPA RI/FS Guidance for CERCLA sites (USEPA, 1988). Various databases, technical reports, and publications (refer to Section 4.2 "Sources and Methods for Identification of Potentially Applicable Technologies") were used to conduct a search to identify applicable technologies. Next, for each GRA, technology classes that encompass the means for achieving the GRAs were selected. The selected technology classes were expanded into lists of potentially applicable process options. The technologies identified and evaluated during this FS may be supplemented by other technologies during the design phase for OU3.

As an initial screening, the list of process options was refined by evaluating each process option in terms of technical implementability. In this step, process options that were clearly ineffective or unworkable at the Site were eliminated. Technologies and process options that were retained after the initial screening were submitted to a second screening process and evaluated in terms of effectiveness, implementability, and relative costs. The implementability evaluation for the second screening step places a greater emphasis on the institutional aspects of implementability, such as the ability to obtain necessary permits, the availability of treatment, storage, and disposal services, and the availability of necessary equipment and skilled workers to implement the technologies. Technologies that were retained after the second screening were then used to assemble remedial alternatives, as discussed in Section 5.0.

4.1. General Response Actions

GRAs are broad classes of responses or remedies developed to meet the RAOs. The GRAs consider the nature of the contamination (i.e., dissolved in groundwater and diffused into or sorbed onto the rock matrix), the COCs (chlorinated solvents, dioxins/furans, inorganics [primarily arsenic and lead] and PCBs), the physical and hydrogeological characteristics of the Site, and existing Site infrastructure. Seven GRA's have been identified for OU3:

- No Action
- Institutional Controls
- Monitored Natural Attenuation (MNA)
- *In Situ* Treatment
- Containment

- *Ex Situ* Treatment
- Groundwater Disposal Options

Although commonly used as a GRA for groundwater at other CERCLA sites, extraction was not considered to be an applicable GRA for OU3. Extraction GRAs are designed to collect contaminated groundwater for subsequent treatment with the goal of reducing the volume or toxicity of contaminants. Containment GRAs may also include groundwater removal (or extraction). However, although both extraction and containment GRAs may involve removal (or extraction) of groundwater, the goal of an extraction GRA is to maximize contaminant mass removal, whereas the goal of a containment GRA is to prevent contaminant mass from migrating to receptor areas. This distinction is significant because it drives the design of a pump-and-treat system, including number and placement of extraction wells, and optimal groundwater extraction rates (extraction rates are typically higher for extraction GRAs than for containment GRAs). The groundwater extraction GRA is not applicable at OU3 because most of the contaminant mass is present in the rock matrix and thus not available for extraction; a pump-and-treat system designed to remove contaminant mass at OU3 would likely be operated for many years (at a much higher pumping rate than a containment system) and would be inefficient, as the rate of mass removal would be dictated by the rate of contaminant mass diffusion out of the rock matrix.

No Action

Consideration of a 'No Action' response action is required by the NCP. The No Action response serves as a baseline against which the performance of other GRAs may be compared. Under the No Action response, no remedial actions would be performed to reduce the toxicity, mobility, or volume of contaminated groundwater. No institutional controls would be implemented either on-Site or off-Site as part of the No Action GRA.

Institutional Controls

Institutional controls are legal or administrative measures designed to prevent or reduce human exposure to hazardous substances. Such measures may include groundwater use restrictions and provision of an alternate water supply. Institutional controls are often implemented in conjunction with other remedy components. For OU3, an institutional control may include establishment of a classification exception area (CEA) in accordance with New Jersey regulations.

Monitored Natural Attenuation

This GRA relies on natural mechanisms including dispersion, dilution, adsorption, and biodegradation to reduce contaminant concentrations in groundwater. There is no intervention to manipulate the physical, geochemical, or hydrological regime. Comprehensive monitoring is a required component of this GRA to evaluate and verify

the progress of MNA, as is a contingency plan that defines the appropriate response action(s) should MNA not perform as expected.

In Situ Treatment

In situ treatment technologies may be used to reduce contaminant concentrations without removal or containment of groundwater. Many *in situ* treatment options are typically applied only for source areas (e.g., thermal treatment, *in situ* chemical oxidation). Other *in situ* treatment options may also be applied at areas of lower contaminant concentration (e.g., *in situ* bioremediation).

Containment

Groundwater containment is typically achieved using physical vertical barriers, surface caps to limit precipitation infiltration, or hydraulic controls (e.g., interceptor trenches and extraction wells). Containment actions are taken to inhibit further migration of contaminated groundwater by minimizing recharge to the groundwater table and/or altering the groundwater flow direction (i.e., minimizing mobility of contaminants). Containment options typically are not aimed at reducing the volume or toxicity of contaminants; however, containment that involves groundwater extraction and treatment would also result in reducing the volume of contaminants existing in the fracture water.

Ex Situ Treatment

Ex situ treatment GRAs are typically paired with GRAs involving collection of contaminated groundwater. The goal of *ex situ* treatment is to reduce concentrations of contaminants in groundwater to levels required for the selected discharge process option. *Ex situ* treatment includes technologies that involve biological and physical/chemical processes, as well as transport for off-Site treatment.

Groundwater Disposal Options

Groundwater disposal GRAs are typically paired with GRAs involving collection of contaminated groundwater. Extracted groundwater could be transported to a permitted Resource Conservation and Recovery Act (RCRA) treatment/storage/disposal facility (TSDF) or discharged to a publicly owned treatment works (POTW) for treatment. Alternatively, the groundwater could be treated on-Site using *ex situ* treatment and then discharged to a POTW, to a nearby surface water body, or injected into the subsurface via deep well injection.

4.2. Sources and Methods for Identification of Potentially Applicable Technologies

Several databases, guidance documents, and journal articles addressing remediation in fractured bedrock were used to identify potentially applicable remedial technologies for OU3. The following sources are of particular note:

- Federal Remediation Technologies Roundtable (FRTR) website (http://www.frtr.gov/matrix2/top_page.html)
- USEPA Hazardous Waste Clean-up Information web site – fractured bedrock project profiles: (<http://www.clu-in.org/products/fracrock/>)
- Fractured Rock: State of the Science and Measuring Success in Remediation (National Ground Water Association, September 2005)
- DNAPL Source Reduction: Facing the Challenge (ITRC, April 2002)
- Critical Review of State-of-the-Art In Situ Thermal Technologies for DNAPL Source Zone Treatment (ESTCP, 2010)
- Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites (USEPA, 1996)

4.3. Technology Identification and Technical Implementability Screening

The following sub-sections describe the technology classes and process options that encompass the means for achieving the GRAs. For example, *in situ* treatment is a GRA that may achieve RAOs using thermal treatment, *in situ* chemical oxidation (ISCO), or biological remediation technologies. Specific process options were identified within each technology class. For instance, ISCO, which is a technology class, includes process options related to the type of oxidant selected, such as permanganate, hydrogen peroxide, or sodium persulfate. Applicable process options were selected based on an understanding of the characteristics of the contaminated media and the technologies that are available to address the media.

The universe of potentially applicable technology types and process options was reduced by screening the technologies and process options with respect to technical feasibility for OU3. This was accomplished by using the information collected during the RI regarding the Site geology and contaminant concentrations and distribution. The major factors that influence the technical feasibility of remedial technologies at OU3 are the complex geology (fractured rock), depth of contamination (greater than 100 feet below ground surface), and the commingled presence of various contaminant classes. Also, the high concentrations of chlorinated solvents suggest the presence of DNAPL, and rock matrix testing has shown that chlorinated ethenes are present within the rock matrix, where they are not easily accessible for extraction or treatment. Table 4-1 lists the identified technologies and process options and summarizes the outcome of the technical implementability screening. Results of the preliminary screening of technologies and process options identified for each GRA are also discussed below.

4.3.1. GRA: No Action

Under the No Action response, no remedial actions would be performed to reduce the toxicity, mobility, or volume of contaminated groundwater. No institutional controls would be implemented either on-Site or off-Site as part of the No Action GRA. The NCP requires that the No Action alternative be developed as one of the potential remedial actions to be considered in a Feasibility Study. Therefore, the no action response will be retained for further evaluation.

4.3.2. GRA: Institutional Controls

The remedial technology identified under the Institutional Controls GRA consists of administrative restrictions focused on minimizing potential contact with contaminated groundwater. The process option includes groundwater use restrictions that could be accomplished by establishing a groundwater CEA through NJDEP. This process option is technically feasible and has been retained for further screening.

4.3.3. GRA: Monitored Natural Attenuation

This GRA relies on natural mechanisms including dispersion, dilution, adsorption, and biodegradation to reduce contaminant concentrations in groundwater. There is no intervention to manipulate the physical, geochemical, or hydrological regime. The process option associated with MNA consists of monitoring groundwater quality with existing or newly installed wells to verify the progress of MNA. This process option is technically feasible and therefore, was retained for further evaluation.

4.3.4. GRA: In Situ Treatment

The remedial technologies identified under this GRA consist of measures to treat contaminated groundwater *in situ* (i.e., without removal). The technology classes and associated process options screened under this GRA are described below.

4.3.4.1. Technology Class: Thermal Treatment

Several thermal treatment technologies are identified that may be applicable for use at OU3. Although many of these treatment technologies have been proven to treat chlorinated solvent DNAPL, PCBs, pesticides and PAHs, there have been only one or two applications in fractured bedrock.

Steam-Enhanced Extraction: Steam-enhanced extraction (SEE) uses an alternating steam injection and vacuum extraction approach to remove volatile and semi-volatile compounds from the subsurface. The steam injection displaces mobile liquids (groundwater and mobile NAPL) ahead of the advancing steam zone. Liquids displaced by the injected steam are pumped from extraction wells. The vapors containing the volatilized contaminants are captured by vacuum extraction. Once above ground, extracted groundwater and vapors are cooled and condensed. Liquid hydrocarbons are separated from the aqueous steam for recycling, and process vapors and water are treated before discharge.

Steam is the cheapest form of energy for *in situ* thermal treatment because typical boiler efficiencies range from 80 to 90%. However, SEE application in fractured sedimentary rock is complicated because it is difficult to achieve hydraulic and pneumatic control. Steam entering fractures typically gives up heat fairly quickly; large heat losses along fractures lead to rapid condensation and short travel distances of steam, limiting treatment effectiveness. The presence of most of the contaminant mass within the rock matrix complicates any technology that relies on contaminant flow through fractures during remediation. For SEE, when the fractures are initially filled with steam or hot condensate, temperature gradients will be inward towards the matrix block centers, potentially discouraging diffusion out of the matrix. After heat-up is accomplished, pressure cycling is hoped to enhance mass removal by boiling the pore water in the matrix. However, the effects of heat transport from fractures on contaminants within rock matrices have not been researched, and are largely unknown (USEPA, 2005).

Several SEE applications have been performed at large sites. MCL level groundwater concentrations have been achieved at two sites, leading to site closure. Relatively new thermal treatment schemes involving combinations of SEE with thermal conduction heating (TCH) seek to optimize the use of the lower-energy method (i.e., by enhancing electrical heating projects using steam injection). Therefore, SEE will be retained for further evaluation, especially in the context of combining SEE with electrical heating.

Electrical Resistance Heating: Electrical resistance heating (ERH) involves installation of electrodes in the subsurface. Soil and groundwater are heated by the passage of electrical current between the electrodes. It is the resistance to the flow of electrical current that results in increased subsurface temperatures. The maximum achievable temperature with ERH is the boiling point of water. As the subsurface is heated, contaminants are volatilized and soil moisture and groundwater are converted to steam. Above ground treatment involves treating vapors, condensate, and entrained water.

Unlike SEE, ERH does not rely on fluid movement to deliver heat, and therefore may be more applicable to the dual-porosity matrix at OU3. ERH electrodes are constructed using readily available materials (e.g., steel pipe, sheet piling) and have been used to treat contamination to depths of 100 feet bgs (ESTCP, 2010). Over 75 ERH applications have been completed, including several DNAPL applications. A literature search revealed documentation of only one ERH application in fractured bedrock. This application was deemed to be successful (reduction of groundwater concentrations by 98%), but it was a fairly shallow application (i.e., treatment of bedrock depth 20 to 28 feet bgs). ERH is potentially technically implementable at OU3 and has been retained for further evaluation.

Dynamic Underground Stripping and Hydrous Pyrolysis Oxidation: Dynamic Underground Stripping and Hydrous Pyrolysis Oxidation (DUS/HPO) combines several technologies to remediate groundwater contaminated with organic compounds. Steam is injected at the periphery of a contaminated area to heat permeable subsurface areas, vaporize volatile compounds bound to the soil, and drive contaminants to centrally

located vacuum extraction wells. ERH is used at less permeable areas to vaporize contaminants and drive them into the steam zone. HPO occurs when steam and air are injected in paired wells. When injection is halted, the steam condenses and contaminated groundwater returns to the heated zone, where it mixes with oxygen-rich condensed steam, and contaminants in the groundwater are oxidized.

HPO/DUS has been used to remediate DNAPL in the field, and laboratory studies have been successful for TCE and PCBs. HPO/DUS is a labor-intensive process, requiring significant field expertise to implement. There is no case study information for the application of this technology in fractured rock. This technology combines elements of the other technologies already being evaluated (i.e., ERH and SEE); therefore, HPO/DUS will not be retained for further evaluation.

Thermal Conduction Heating: Thermal conduction heating (TCH), also known as *in situ* thermal desorption (ISTD), is the simultaneous application of heat and vacuum to the subsurface to remove organic contaminants. Heat is applied by installing electrically powered heaters throughout the zone to be treated. The heat moves out into the inter-well regions primarily via thermal conduction. In fractured rock systems, boiling of fluids in the fractures and within the rock matrix leads to steam formation. The steam is captured by the vacuums applied at each heater boring. TCH may be applicable for higher boiling point organics such as PCBs, PAHs, and pesticides because it can heat the subsurface to temperatures exceeding 300 degrees Celsius (°C) assuming that the amount of water in the treatment area can be controlled, because water has a cooling effect on the treatment area.

Similar to ERH, TCH does not rely on fluid movement to deliver heat, and therefore may be more applicable to the dual-porosity matrix at OU3. TCH has been applied successfully to treat DNAPL in a gneiss bedrock (Heron et al., 2008). It has also been applied recently to treat DNAPL in a fractured mudstone at a demonstration project site located at the former Naval Air Warfare Center (NAWC) in Trenton, New Jersey. The initial results of this application are promising (TerraTherm, 2010). TCH is retained for further evaluation because it is potentially technically implementable at OU3.

4.3.4.2. Technology Class: Biological Treatment

Bioremediation is a technology in which the physical, chemical, and biological conditions of a contaminated medium are manipulated to accelerate the natural biodegradation and mineralization processes. Biodegradation is the process whereby microorganisms alter the structure of a chemical, while mineralization is the complete biodegradation of a chemical to carbon dioxide, water, and simple inorganic compounds. In nature, both partial biodegradation and complete mineralization take place; the processes, however, are frequently slow. Biodegradation and mineralization are potentially applicable only to the organic COCs present at OU3 (i.e., CVOCs, PCBs, pesticides, dioxins/furans and SVOCs). Furthermore, heavier, more chemically complex organic compounds tend to be recalcitrant to biodegradation and mineralization (e.g.,

PCBs, dioxins/furans). Biostimulation and bioaugmentation are two processes used to enhance the rates of biodegradation and mineralization. Biostimulation involves the addition of amendments such as carbon substrates and nutrients to stimulate biodegradation. Bioaugmentation involves the addition of engineered microbes that are known to degrade the contaminants of interest.

Enhanced Reductive Dechlorination via Biostimulation: Reductive dechlorination is the most important process in the natural biodegradation of chlorinated solvents. For reductive dechlorination to completely degrade chlorinated VOCs such as TCE and cis-DCE, the geochemical conditions in the subsurface must be ideal and microorganisms that are capable of degrading the chlorinated VOCs must be present. During the RI, laboratory microcosm studies were performed as a screening-level assessment of whether biostimulation would be an effective remedy at OU3. Twenty-one groundwater samples were collected from FLUTETM wells during the March 2010 sampling event and shipped to Bioremediation Consulting, Inc. The purpose of the microcosm study was to demonstrate whether dechlorinating bacteria were active in the samples by the addition of amendments to optimize conditions for reductive dechlorination. Carbon substrates including sodium lactate, emulsified vegetable oil (EVO), and corn syrup (glucose and fructose) were added to each microcosm, as well as nutrients (ammonia, nitrate, and vitamin B12). The data showed that every microcosm contained anaerobic sulfate-reducing bacteria, nine microcosms contained methanogens, and 11 samples contained microbes capable of dechlorinating TCE to cDCE. Microcosms with groundwater collected from four ports (MW-14D-01, MW-14S-04, MW-16-05, and MW-16-07) produced VC and ethene, implying that the bacterium *Dehalococcoides ethenogenes* (DHE) was active in those four samples (see Appendix B for the full report containing the microcosm data). To date, the complete sequential dechlorination of TCE to ethene has been demonstrated only for DHE.

A full-scale approach for enhanced reductive dechlorination (ERD) at OU3 would involve injection of a carbon substrate to promote achievement of appropriate geochemical conditions in the subsurface and to foster growth of the dechlorinating bacteria. This process has been used successfully to treat chlorinated ethenes at numerous sites, including fractured bedrock settings. ERD via biostimulation is technically feasible and will be retained for further evaluation.

Enhanced Reductive Dechlorination via Bioaugmentation: Bioaugmentation involves the addition of non-native organisms known to degrade the contaminants of interest. Bioaugmentation is typically conducted in concert with biostimulation. Bioaugmentation may be used at a site when the presence of an appropriate population of microbes is not present or sufficiently active to stimulate complete degradation. As discussed above, the microcosm study indicated that dechlorinating bacteria are present at some locations; however, other locations did not exhibit the presence of functional dechlorinating bacteria. Also, the microcosms were designed to investigate the presence of bacteria for chlorinated ethene degradation only. Heavier organic compounds (i.e., PCBs, PAHs, pesticides) are more recalcitrant to microbial degradation. However, microbial cultures

have been developed to target these more recalcitrant compounds. Although field experience with bioaugmentation is more limited than biostimulation alone, this process option is technically feasible and will be retained for further evaluation.

4.3.4.3. Technology Class: In Situ Chemical Oxidation

In situ chemical oxidation (ISCO) involves the delivery and distribution of oxidants and other amendments into the subsurface to transform COCs into innocuous end products such as carbon dioxide, water, and inorganic compounds. The appropriateness of ISCO technology at a site depends on matching the oxidant and delivery system to the site contaminants and site conditions. For ISCO to be effective, the oxidant must come into direct contact with COCs. The most common oxidants utilized for ISCO are permanganate, catalyzed hydrogen peroxide (CHP), and activated persulfate. Each of these oxidants was evaluated as a potentially feasible process option.

ISCO with Permanganate: Permanganate is an oxidizing agent with a unique affinity for oxidizing organic compounds with carbon-carbon double bonds (e.g., TCE and cis-DCE). There are two forms of permanganate that are used for in-situ chemical oxidation: potassium permanganate (KMnO_4) and sodium permanganate (NaMnO_4). Potassium permanganate is available as a dry crystalline material, while sodium permanganate is a liquid. Permanganate turns bright purple when dissolved in water; this purple color acts as a built-in indicator for unreacted chemical. Reacted permanganate is black or brown, indicating the presence of a manganese dioxide (MnO_2) byproduct. Compared to the other commonly used oxidants, permanganate is more stable in the subsurface. Unlike CHP, permanganate does not degrade naturally and can persist in the subsurface indefinitely (i.e., it is only consumed by interaction with contaminants or natural organic material). The persistence of permanganate in the subsurface allows for diffusion of the oxidant into the subsurface matrix – making treatment of less permeable materials (i.e., clay or sedimentary rock) possible over time. ISCO with permanganate will be retained for additional evaluation.

ISCO with CHP: CHP involves the injection of hydrogen peroxide under acidic conditions in the presence of a ferrous iron catalyst to form hydroxyl free radicals. Hydroxyl radicals are very effective and nonspecific oxidizing agents. However, they are unstable and have a fairly short active life (i.e., on the order of hours or a few days). This short active life is not conducive to the longer diffusive time scales required to treat the rock matrix at OU3. In addition, it could prove difficult to effectively catalyze the peroxide with the ferrous iron in fractured rock because each reagent is injected separately, and mixing may be inadequate within narrow and dead-end fractures. Therefore, ISCO with CHP has not been retained for further evaluation.

ISCO with Activated Persulfate: Sodium persulfate dissociates in water to form the persulfate anion ($\text{S}_2\text{O}_8^{2-}$) which, although a strong oxidant, is kinetically slow in oxidizing many organic contaminants. When catalyzed or 'activated' in the presence of high pH (e.g., via addition of sodium hydroxide $[\text{NaOH}]$), heat (thermal catalyzation), a

ferrous salt, or hydrogen peroxide, the persulfate ion is converted to the sulfate free radical ($\text{SO}_4^{\cdot-}$). The sulfate free radical is a very potent oxidizing agent that has a greater oxidation potential and can degrade a wider range of environmental contaminants at faster rates than the persulfate anion. Formation of $\text{SO}_4^{\cdot-}$ may also initiate the formation of the hydroxyl free radical, another strong oxidizing agent, as well as a series of radical propagation and termination chain reactions whereby organic compounds may be transformed. Persulfate is an attractive oxidant for DNAPL treatment because it persists in the subsurface, can be injected at high concentrations, and will undergo density-driven and diffusive transport into low-permeability materials. ISCO with activated persulfate has been retained for further evaluation.

4.3.4.4. Technology Class: Permeable Reactive Barriers

Permeable reactive barriers (PRBs) are installed across the flow path of a contaminant plume, allowing the water portion of the plume to passively move through the wall. These barriers allow the passage of water while inhibiting the movement of contaminants by employing such reactive agents as zero-valent metals, chelators (ligands selected for their specificity for a given metal), sorbents, microbes, and other reactive media. The majority of installed PRBs use zero-valent iron (ZVI) as the reactive medium for the treatment of chlorinated ethenes. As the iron is oxidized, a chlorine atom is removed from the chlorinated ethene by one or more reductive dechlorination mechanisms, using electrons supplied by the oxidation of iron. The iron granules are dissolved by the process, but the metal disappears so slowly that the remediation barriers can be expected to remain effective for many years, possibly even decades. PRBs are generally intended for long-term operation to control migration of contaminants in groundwater. Granular ZVI and nano-scale ZVI were evaluated as process options for PRBs at OU3.

PRB using Granular ZVI: The granular iron used in most PRB applications comprises a mixture of ductile and cast iron cuttings obtained from a number of primary industries that use iron in the production of automotive and related industrial parts. A number of these “feedstocks” are mixed together, put through a rotary kiln in the presence of proprietary gas mixtures, cooled, milled, and sorted to a specific grain size range. Higher grain sizes are used for PRBs constructed using excavation methods where the ZVI is placed directly into a trench. Smaller grain sizes are used for PRBs constructed using injection technologies (e.g., hydraulic fracturing, high-pressure jetting, or liquid atomized injection). Given the depth of contamination at OU3 and the fractured rock setting, it is not feasible to install a PRB using conventional excavation equipment. Although ZVI emplacement via high-pressure jetting or liquid atomized injection was considered, it is technically infeasible to accurately emplace a continuous barrier in fractured rock. The presence of fractures could create multiple pathways for groundwater to circumvent the granular ZVI medium. Therefore, use of a PRB with granular ZVI will not be retained for further evaluation.

PRB using Nano-Scale ZVI: Nano-scale ZVI is composed of sub-micrometer particles of iron metal (typically 10 – 1000 nanometers). Nano-scale ZVI is highly reactive

because of its large surface area. Nano-scale ZVI is a developing technology. One of the issues associated with the use of nano-scale ZVI is that the particles have a tendency to agglomerate and settle out of the transport solution. In addition, the particles are denser than water, which also gives them a tendency to settle in solutions. Various techniques have been applied to improve nano-scale ZVI stability in solution: emulsification of the particles; suspension in guar gum, suspension in polymers, and others. Typically, nano-scale ZVI is distributed to the subsurface using injection wells. Very few applications of nano-scale ZVI in fractured rock have been implemented. It is anticipated that it would be difficult to ensure iron distribution throughout the fracture network and to prevent flushing of the iron with advective groundwater flow, which can be very significant in major flow zones. Therefore, use of a PRB with nano-scale ZVI will not be retained for further evaluation.

4.3.4.5. Technology Class: Enhanced Desorption and Treatment

Enhanced desorption refers to approaches to enhance DNAPL and dissolved mass removal involving the injection and subsequent extraction of chemicals or air. Chemicals may be injected into a system of wells designed to “sweep” the DNAPL zone within the aquifer. The chemical “flood” and the solubilized or mobilized DNAPL is removed through strategically placed extraction wells. The produced liquids are then treated and either disposed or returned to the subsurface. The chemicals used are typically aqueous surfactant solutions or cosolvents (e.g., alcohols). When using surfactants, the process is referred to as Surfactant-Enhanced Aquifer Remediation (SEAR). When co-solvents are used, the technology is referred to as co-solvent flooding. Both technologies lower the interfacial tension between DNAPL and the injected chemical(s). Air sparging involves the injection of air into the aquifer to gasify contaminants and thus mobilize them into the air stream, which is then extracted and treated at the surface.

Surfactant-Enhanced Aquifer Remediation (SEAR): SEAR involves the preparation of low viscosity surfactant solutions that are pumped through the DNAPL contaminated zone by introduction at injection points and removal from extraction points. Detailed site characterization is necessary to define DNAPL zone boundaries and to understand the hydrostratigraphy of the zones to be flushed to avoid unintended DNAPL migration. Hydraulic continuity between the injection and extraction points is required to recover the mobilized DNAPL and the injectants. This hydraulic continuity is difficult to obtain in a fractured rock setting. Also, the surfactants are not expected to mobilize contaminant mass that has diffused into the rock matrix. Therefore, SEAR will not be considered for further evaluation.

Co-Solvent Flooding: Co-solvents, usually alcohols, are chemicals that dissolve in both water and NAPL. In an alcohol flood, the alcohol may partition into both the NAPL and water phases. Partitioning affects the viscosity, density, solubility, and interfacial tension of the NAPL. The physical properties of the NAPL vary with the amount of alcohol available for interaction, and whether the alcohol preferentially dissolves into the NAPL or into the water. Complete miscibility is achievable and results in a pumpable solution that, depending upon the density of the NAPL and the proportions of alcohol and water in

the solution, may be more or less dense than water. As with SEAR, the success of co-solvent flooding depends on whether hydraulic continuity is maintained between the injection and extraction points. Because of the great uncertainty involved in maintaining hydraulic connectivity in fractured rock, co-solvent flooding will not be considered for further evaluation.

Air Sparging: Air sparging involves injection of a gas (typically air) under pressure into the saturated zone to volatilize groundwater contaminants. Volatilized vapors migrate into the vadose zone where they are extracted under vacuum, generally by a soil vapor extraction system. Air sparging has been used at many sites to treat chlorinated ethenes, including DNAPL. Successful use of air sparging technology depends on the ability of the system to effectively deliver air to the treatment area and the ability of the subsurface media to transmit the air. Heterogeneous conditions, such as the presence of multiple fractures, limit the effectiveness of this technology because the fractures create preferential flowpaths for the air. This technology would not be effective at removing contaminants from smaller fractures, and also would not treat contaminants diffused into or sorbed onto the rock matrix. Therefore, air sparging will not be considered for further evaluation.

4.3.5. GRA: Containment

Containment technologies can mimic source treatment by preventing the migration of contaminants to existing or potential downgradient receptors. Containment technologies include hydraulic control, caps, and vertical barriers, such as sheet piles or slurry walls. These technologies provide hydraulic containment by preventing the migration of groundwater from a source area. The technology classes and associated process options screened under this GRA are described below.

4.3.5.1. Technology Class: Hydraulic Control

Extraction Wells: Hydraulic control may be achieved by controlling the direction of groundwater flow with capture zones, which are points of low hydraulic head to which nearby groundwater flows. When groundwater is pumped from extraction wells, the groundwater potentiometric surface is modified. By optimizing the locations of the extraction wells and adjusting the groundwater pumping rates, a potentiometric surface can be manipulated to prevent groundwater carrying contaminants from migrating to receptors. This technology has been used at many sites including fractured rock settings, and is technically feasible for OU3. The water that is extracted typically requires treatment and subsequent disposal. Process options for *ex situ* groundwater treatment and discharge are discussed in Sections 4.3.6 and 4.3.7, respectively. Hydraulic control using groundwater extraction wells will be retained for further evaluation.

Interceptor Trenches: Interceptor trenches refer to a wide range of lateral groundwater collection systems from tile-drain systems to deep horizontal well installations. Recent technology advances in trench construction methods, such as continuous trenching equipment, use of biodegradable slurries, geotextiles or plastic shoring materials, and other innovations have led to the more frequent use of interceptor trenches. All of these

construction methods involve the installation of a horizontal collection system which intersects a large cross-section of an aquifer. Groundwater is directed to the interceptor trench as a result of a hydraulic head drop maintained across the length of the trench. The hydraulic head drop can be a result of gravity drainage (as in a traditional French Drain) or can be induced by pumping from a collection sump attached to the trench system. Interceptor trenches are typically used in shallow groundwater collection applications in unconsolidated media. This technology is not feasible for use at OU3 because it would require deep trenching through fractured rock. Therefore, interceptor trenches will not be retained for further evaluation.

4.3.5.2. Technology Class: Vertical Barrier

Slurry Wall: Slurry walls consist of a vertically excavated trench that is filled with a low-permeability slurry material. Most slurry walls are constructed of a soil, bentonite, and water mixture. The bentonite slurry is used primarily for wall stabilization during trench excavation. A soil-bentonite backfill material is then placed into the trench (displacing the slurry) to create the cutoff wall. Walls of this composition provide a barrier with low permeability and chemical resistance. Other wall compositions, such as cement/bentonite, pozzolan/bentonite, attapulgit, organically modified bentonite, or slurry/geomembrane composite, may be used if greater structural strength is required or if chemical incompatibilities between bentonite and site contaminants exist. Slurry walls are typically placed at depths up to 100 feet in unconsolidated media and are generally 2 to 4 feet in thickness. This technology is not feasible for use at OU3 because it would require deep trenching through fractured rock. Therefore, slurry walls will not be retained for further evaluation.

Grout Curtain: Another method used to create a vertical barrier to groundwater flow is the installation of a grout curtain. Grouting consists of the injection of one of a variety of special fluids (e.g., epoxy, sodium silicate) or particulate grouts (e.g., Portland cement), into the soil matrix under high pressure. Grouting reduced permeability and increases mechanical strength of the grouted zone. When carried out in a linear pattern, grouting can result in a curtain or wall that can be an effective barrier to groundwater flow. The rate of grout injection and the spacing between the injection wells are critical. If the rate of injection is too slow, premature solidification occurs and if the injection rate is too fast, the formation may be fractured. The advantage of grout curtain emplacement is the ability to inject grout through relatively small diameter drill holes at unlimited depths. The main disadvantage of using grout curtains is the uncertainty that complete cutoff is attained. Given the highly fractured nature of the rock at OU3, it is unlikely that complete cutoff could be attained with a grout curtain; therefore, this process option will not be retained for further evaluation.

Sheet Piling: Sheet pile cutoff walls are constructed by driving sheet materials, typically steel, through unconsolidated materials with a pile driver or vibratory drivers. This technology is not feasible for OU3 because it is technically infeasible to drive sheet pile material into consolidated rock. Therefore, sheet piling will not be retained for further evaluation.

4.3.5.3. Technology Class: Capping

Capping prevents or reduced infiltration of rainwater to the aquifer. Caps (or covers) which involve installing low-permeability material at the ground surface, are typically constructed of soil and synthetic material, asphalt, or bituminous concrete.

Multimedia Cap: A multimedia cap is typically constructed from low-permeability clay and synthetic membrane covered by soil to minimize groundwater recharge. Although this process option is implementable at OU3, the remedial action currently underway for OU2 at the CDE (i.e., on-Site soil) already includes installation of an asphalt cap over the majority of the former CDE facility. Therefore, installation of a multimedia cap will not be retained for further evaluation.

Asphalt or Concrete Cap: This process options involves the installation of a layer of asphalt or a concrete slab over portions of OU3 to minimize groundwater recharge. As discussed above, the remedy for OU2 already includes installation of an asphalt cap over the majority of the former CDE facility. Therefore, installation of an asphalt or concrete cap would not be necessary for an OU3 remedy, and will not be retained for further evaluation.

4.3.6. GRA: Ex Situ Treatment

Ex situ treatment may be required when the selected remedy involves groundwater extraction, and when the groundwater requires on-site treatment prior to discharge (see Section 4.3.7). Although the technologies employed for treating extracted groundwater are important aspects of the remedy, they have little influence on reducing contaminant levels or minimizing contaminant migration at OU3. Therefore, the technologies presented in USEPA's *Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites* (1996) are evaluated. These presumptive *ex situ* treatment technologies are well-understood methods that have been used for many years in the treatment of drinking water and/or municipal or industrial wastewater. The presumptive technologies presented below are the technologies retained for the development of remedial alternatives. The presumptive response guidance document serves as the FS technology screening step (USEPA, 1996) for the *ex situ* treatment component of a remedy.

The presumptive technologies for treatment of extracted groundwater containing dissolved organic contaminants include the following:

- Air stripping
- Granular activated carbon
- Chemical / Ultraviolet (UV) oxidation
- Aerobic biological reactors

The presumptive technologies for treatment of dissolved metals include the following:

- Chemical precipitation
- Ion exchange/adsorption

The reader is referred to Appendix C, which contains an excerpt from the presumptive response guidance document (USEPA, 1996), providing descriptions, advantages, and disadvantages of these technologies. In addition to the presumptive technologies listed in the guidance, other treatment components may be needed prior to (pretreatment) or subsequent to (post-treatment) the presumptive technologies. These could include pH adjustment, methods for separation of oil and/or grease from water, and filtration technologies to remove solid particles (e.g., resulting from chemical precipitation, from oxidation, or other processes). These ancillary components are not addressed in detail in this FS, but may be used to assemble *ex situ* treatment alternatives, as needed.

4.3.7. GRA: Groundwater Disposal Options

Groundwater discharge or disposal would be required if the remedy for OU3 involved groundwater extraction. The primary options for groundwater disposal include on-Site treatment followed by discharge to surface water, a POTW, or deep well injection or transport to an off-Site location (e.g., POTW or RCRA TSDF) for treatment and disposal. These options are described and evaluated below.

4.3.7.1. Technology Class: Off-Site Treatment

Publicly Owned Treatment Works (POTW): This process option involves the direct discharge of untreated extracted groundwater to a local POTW for treatment. Wastewater from the CDE facility is directed to a wastewater treatment facility operated by the Middlesex County Utilities Authority (MCUA). MCUA's discharge limitations are included in Appendix D. Given the high concentrations of toxic organics (in particular chlorinated ethenes and PCBs) in the groundwater at OU3, pre-treatment would be required prior to discharge to MCUA facilities, which then puts this technology into the Discharge of Treated Water technology class (see section 4.3.7.2). Therefore, discharge of untreated groundwater to a POTW will not be retained as a process option.

RCRA Treatment/Storage/Disposal Facility: This process option involves the transport of extracted groundwater to a licensed RCRA facility for treatment and/or disposal. This process option is not technically feasible based on the volumes of water anticipated to be extracted for a hydraulic containment remedy (likely on the order of 30 to 50 gallons per minute [gpm]). Therefore, this process option will not be retained for further evaluation.

4.3.7.2. Technology Class: Discharge of Treated Water

Discharge to Surface Water: This process option involves the discharge of treated groundwater to Bound Brook. Surface water and sediment in Bound Brook have been designated as OU4 of the CDE Superfund Site. Investigation and remediation activities for OU4 may be on-going over the next several years; therefore, discharge to Bound Brook would need to be designed to avoid interference with these activities. Currently,

the NJDEP classifies the Bound Brook reach within the Bound Brook Corridor as FW-2 non-trout waters. Discharge to Bound Brook would necessitate treatment of groundwater to meet effluent criteria required for FW-2 waters, which are more stringent than those specified by MCUA (see Appendix E). Discharge of treated groundwater to Bound Brook is retained for further evaluation because it may be technically feasible.

Discharge to POTW: This process option entails the discharge of treated groundwater to MCUA for further treatment and disposal. A temporary discharge approval (TDA) would need to be obtained from MCUA, and the *ex situ* treatment system would need to be designed to meet MCUA's discharge limitations (see Appendix D). This process option is technically feasible and will be retained for further evaluation.

Infiltration Basin or Gallery: An infiltration basin allows treated water to seep through the ground surface in a controller area. An infiltration gallery includes a subsurface network of perforated pipes in trenches that return the treated water below the surface, but above the water table. Assuming that an infiltration basin or gallery would be located either on or in the immediate vicinity of the CDE facility, this process option is likely not technically feasible because the top of consolidated bedrock is encountered at four to 15 feet bgs, and it would be infeasible to construct a basin or gallery in fractured rock. Also, an infiltration gallery or basin would need to be located outside of the area of influence of any groundwater capture/containment system and it is likely that the former CDE facility would be within this area of influence. Infiltration basins and galleries are therefore considered technically infeasible and have not been retained for further evaluation.

Deep Well Injection: Deep well injection is a liquid waste disposal technology. This process option involves the use of injection wells to place treated or untreated liquid waste into geologic formations that have no potential to allow migration of contaminants into potential potable water aquifers. This option is only technically feasible if transmissive zones are present deep in the fractured rock, or if the rock is fractured using hydraulic or pneumatic fracturing techniques. This process option is technically feasible and will be retained for further evaluation.

4.4. Effectiveness, Implementability, and Cost Screening of Technology Process Options

Technology process options that were retained after the initial technical feasibility screening are subjected to a further screening based on the three criteria of implementability, effectiveness, and relative cost (see Table 4-2). The three screening criteria are described below.

Implementability

Implementability refers to the technical and administrative feasibility of implementing a particular process option. Technologies that are clearly not applicable to OU3 of the CDE Site were previously screened and rejected (see Table 4-1). Therefore,

consideration of implementability focuses on the administrative implementability of process options, including the following:

- The constructability of the remedial technology or process option under current facility conditions (*Note: For this FS evaluation, it has been assumed that process options will be implemented while the facility is undeveloped following OU2 remedial activities (i.e., simply capped with asphalt with an operating stormwater collection system). Future site development may impact constructability.*);
- The time needed to implement the remedial technology or process option to achieve beneficial results and to satisfy the RAOs; and
- Availability and capacity of off-facility treatment, storage, disposal services.

Effectiveness

Determining the effectiveness of a process option involves the following considerations:

- The ability of the process option to effect reductions in the toxicity, mobility, and/or volume of each of the contaminant types of potential concern;
- How well the process option will handle the estimated areas or volumes of groundwater to be remediated;
- The potential impacts to human health and the environment during the construction and implementation phases; and
- How proven and reliable the process is with respect to the difficult geological conditions and high concentrations of contaminants present at OU3.

Cost

Process options were screened with respect to relative costs for capital costs as well as operations and maintenance (O&M costs). Cost discriminators used for preliminary screening are defined in terms of high, moderate, and low, based on engineering judgment. In accordance with the RI/FS guidance (USEPA, 1988), cost plays a limited role in the preliminary screening of technologies and process options.

Table 4-2 summarizes the evaluation of the technologies and process options with respect to implementability, effectiveness, and relative cost.

4.4.1. No Action

Implementability. The No Action GRA is easily implementable. It may include groundwater monitoring and reporting, but does not include any containment, removal, disposal, or treatment of contaminated groundwater.

Effectiveness. Although chemical specific ARARs are waived within the TI zone, a stringent monitoring program is required to assure that the RAOs are being met. The No Action GRA does not provide a sufficiently robust monitoring program to ensure that RAOs are achieved effectively.

Costs. Costs associated with the No Action GRA include long-term groundwater monitoring and preparation of five-year reviews. Costs are low relative to the costs for other GRAs/process options.

Screening Decision. The No Action GRA is retained to serve as a baseline against which other remedial alternatives may be compared.

4.4.2. Institutional Controls

Implementability. Institutional controls, such as restrictions on installation and usage of new groundwater supply wells and usage of existing supply wells are readily implementable. They may be established through a groundwater CEA administered by the NJDEP.

Effectiveness. The effectiveness of institutional controls in preventing exposure to contaminated groundwater depends on their continued enforcement. Institutional controls do not reduce the mass of contaminants, nor do they prevent further contaminant migration. Institutional controls are commonly implemented in conjunction with other technologies.

Costs. The costs for establishing and implementing institutional controls are low relative to the costs for other process options.

Screening Decision. Institutional controls are retained for further evaluation.

4.4.3. Monitored Natural Attenuation

Implementability. MNA is readily implementable. It is commonly applied at sites with contaminated groundwater, either as a stand-alone technology, or as a polishing step after the effectiveness of active treatment diminishes. MNA is typically applied over long periods of time (e.g., decades).

Effectiveness. The effectiveness of MNA varies depending on the efficacy of the various attenuation mechanisms (i.e., dilution, adsorption, dispersion, biodegradation). At OU3, a significant attenuation mechanism is the diffusion-driven mass transfer of VOC mass into the rock matrix. This mechanism has significantly retarded the contaminant plume front relative to the mean groundwater velocity in the fracture network. As discussed in

Section 2.3, there is evidence that biodegradation via reductive dechlorination is occurring, albeit at a slow rate, most likely due to a lack of a carbon source.

Costs. The capital costs for establishing a groundwater monitoring network are low because it is estimated that the existing monitoring network will suffice with the addition of four new monitoring locations. However, the O&M costs are moderate because the monitoring network is extensive both laterally and vertically (i.e., multilevel sample ports), and because of the large suite of analytes, especially for groundwater, to be collected from beneath the former CDE facility (i.e., VOCs, PCBs, pesticides, metals, etc.).

Screening Decision. MNA is retained for further evaluation as both a stand-alone process option and for use in conjunction with other technologies.

4.4.4. In Situ Thermal Treatment

Three *in situ* thermal treatment technologies were retained after the initial technical feasibility screening. Those technologies are further evaluated below.

4.4.4.1. Steam-Enhanced Extraction (SEE)

Implementability. SEE is readily implementable by several experienced vendors. Steam injection equipment is readily available, and can be rented or purchased depending on the duration of the treatment. Extraction and treatment systems for vapor and water are relatively straightforward for chlorinated ethenes and other organics; however, depending on effluent requirements, elevated lead and arsenic in groundwater at OU3 could complicate treatment. Sufficient space needs to be allotted for the above-ground vapor/water treatment components.

Effectiveness. SEE is effective at mobilizing and removing contaminant mass in porous media. It has been applied primarily in non-consolidated soil media and has achieved good results for DNAPL removal. The effectiveness of SEE may be limited in a fractured environment because it is difficult to achieve hydraulic and pneumatic control. SEE is applicable only in zones where there is adequate permeability to conduct the steam (i.e., highly weathered or fractured zones). SEE has been deployed at fractured bedrock sites at Edwards Air Force Base (AFB) and the former Loring AFB under the auspices of USEPA's Superfund Innovative Technology Evaluation program. At Loring AFB, it was concluded that SEE was not an appropriate technology because of low permeability fractures with low interconnectivity (USEPA, 2005). At Edwards AFB, the test was deemed to be very successful for the vadose zone, but treatment was not continued long enough to heat the aquifer to near steam temperatures, so no conclusions could be drawn on aquifer restoration efficacy in fractured granite (USEPA, 2005).

Costs. Steam generation is the cheapest form of energy for *in situ* thermal treatment because steam boiler efficiencies range from 80 to 90%. The capital costs, which include installation of steam injection wells, temperature monitoring points, and vapor extraction wells, as well as assembly of an above-ground water/vapor treatment train, are high

because drilling is expensive in fractured rock. The O&M costs, which include electricity for steam generation, monitoring, and above-ground water/vapor treatment, are also relatively high (although possibly lower than those of the other thermal treatment options).

Screening Decision. New thermal treatment schemes involve combinations of SEE with TCH or ERH to optimize the use of the lower-energy method by applying SEE to areas of higher permeability. SEE will be retained as a process option for consideration in alternatives assembly, especially in the context of combining SEE with electrical heating.

4.4.4.2. Electrical Resistance Heating (ERH)

Implementability. ERH is currently widely applied at a variety of sites at both pilot and full-scale. Several vendors offer ERH services and have the personnel and equipment to address multiple sites concurrently. ERH electrodes are constructed using readily available materials (e.g., galvanized steel pipe, sheet piling) and have been used to treat contamination to depths of 100 feet bgs (ESTCP, 2010). Because the potential treatment depths are fairly high at OU3 (i.e., over 60 feet bgs), up to four stacked electrodes may be required. To accommodate the stacked electrodes, boreholes that are 10 to 12 inches in diameter may be required. A site-specific evaluation would be needed to determine acceptable electrode separation distances. Electrical utility locations, age, capacity, and rate structures will need to be considered to determine if the existing electrical service has sufficient capacity to provide power for a TCH system. Sufficient space needs to be allotted for the above-ground vapor/water treatment components.

Effectiveness. Unlike SEE, ERH does not rely on fluid movement to deliver heat; therefore, it is potentially applicable in a fractured rock setting. ERH uses heat generated by the resistance of the rock material to the flow of electrical current to raise subsurface temperatures up to the boiling point of water (100°C). ERH electrodes do not get any hotter than the surrounding rock; the electrodes merely direct electrical current into the targeted depth interval(s). ERH is limited by the electrical resistivity of the rock. Rock with low porosity, and thus low water content, has higher electrical resistance. During ERH, volatile compounds transition to the vapor phase and are captured by a vapor recovery system. Because ERH is limited to temperatures of 100°C, it has limited effectiveness for higher boiling point compounds such as PCBs, pesticides, and SVOCs. It is possible to extract fluids from ERH heating boreholes. This keeps fluids moving inward towards the heated zone during operations and reduces risk of spreading contaminants. One application of ERH in fractured bedrock (to a depth of 28 feet bgs) was found during a literature search. Although the treatment was shallow, it was deemed to be a successful application.

Costs. Capital costs include installation of boreholes for electrode placement, temperature monitoring points, and vapor extraction wells, as well as assembly of an above-ground water/vapor treatment train. These costs are relatively high compared to capital costs of other process options. The O&M costs, which include electricity for heat generation, monitoring, and above-ground water/vapor treatment are also relatively high.

Screening Decision. ERH could be applicable for treating high concentrations of organic contaminants present in the vicinity of MW-14 at the former CDE facility. ERH would mostly be applicable above the highly fractured zone at 65 feet bgs because the high water flow in this zone serves as a heat sink. ERH is retained as a process option for consideration in alternatives assembly.

4.4.4.3. Thermal Conduction Heating (TCH)

Implementability. TCH is currently widely applied at a variety of sites at both pilot and full-scale. Several vendors offer TCH services, and have the personnel and equipment to address multiple sites concurrently. TCH heater elements can be accommodated in boreholes with three to four inch diameters. Electrical utility locations, age, capacity, and rate structures will need to be considered to determine if the existing electrical service has sufficient capacity to provide power for a TCH system. Sufficient space needs to be allotted for the above-ground vapor/water treatment components.

Effectiveness. Similar to ERH, TCH does not rely on fluid movement to deliver heat. Conductive heating relies on using electricity applied to heater borings to generate very high temperatures (i.e., $>500^{\circ}\text{C}$) at the heater well. The heat migrates away from the heater borings by a combination of thermal conduction (driven by a temperature gradient) and convection (migration of steam produced by boiling groundwater). The rock fractures are major pathways for the generated vapor to escape and be captured by a vacuum extraction system. In a typical fractured rock application, every heater is supplied with a vapor recovery point, so the entire treatment zone is kept under a vacuum to minimize transport of contaminants out of the treatment zone. Thermal conduction heating can heat dewatered zones to temperatures far above the boiling temperature of water, which makes it possible for thermal conduction heating to treat compounds like PCBs, pesticides, and SVOCs. In instances where permeabilities are high (e.g., fractured zone at 65 feet bgs at MW-14), it is not feasible to dewater the treatment area, and thus attainable temperatures are limited to 100°C . TCH has been applied recently to treat DNAPL in a fractured mudstone at a demonstration project site located at the former NAWC, with promising initial results (TerraTherm, 2010).

Costs. Capital costs include installation of boreholes for heating element placement, temperature monitoring points, and vapor extraction wells, as well as assembly of an above-ground water/vapor treatment train. Drilling costs are likely to be lower for TCH than for ERH because the heater elements can be accommodated in boreholes with three to four inch diameters. These costs are relatively high compared to capital costs of other process options. The O&M costs, which include electricity for heat generation, monitoring, and above-ground water/vapor treatment, are also relatively high.

Screening Decision. TCH could be applicable for treating high concentrations of organic contaminants present in the vicinity of MW-14 at the former CDE facility. TCH would mostly be applicable above the highly fractured zone at 65 feet bgs, because the high water flow in this zone serves as a heat sink. TCH is retained as a process option for consideration in alternatives assembly.

4.4.5. In Situ Bioremediation

4.4.5.1. Enhanced Reductive Dechlorination via Biostimulation

Implementability. Biostimulation accelerates microbial degradation of organic contaminants in groundwater by providing nutrients and/or substrates (electron acceptors) through a well system. There are numerous vendors providing various substrates. The substrates most commonly used to enhance anaerobic biodegradation of chlorinated ethenes include lactate, molasses, Hydrogen Release Compound (HRC[®] - available in several formulations), and vegetable oils (neat and emulsified). These substrates may be classified as soluble substrates (e.g., lactate and molasses), viscous fluids (e.g., HRC[®] and neat vegetable oils), low viscosity fluids (e.g., vegetable oil emulsions), and solid substrates (e.g., mulch and compost) (AFCEE et al., 2004). Many of these substrates have been applied at other sites in New Jersey, and thus have been approved for use by the NJDEP. A potential hurdle to implementability is the ability to distribute the substrate effectively throughout the fracture system. This could be accomplished by using a packer assembly to inject the substrate at multiple depth intervals.

Effectiveness. Bench microcosm studies performed during the RI demonstrated that, under optimal conditions for anaerobic biodegradation (i.e., addition of carbon substrate and nutrients), complete transformation of TCE to ethene occurred in groundwater samples collected from MW-14D-01, MW-14S-04, MW-16-05, and MW-16-07 (BCI, 2010). The complete dechlorination of TCE to ethene indicates that dechlorinating bacteria are naturally present at these locations. Also, it was hypothesized that, because samples from MW-14S-01 and MW-14S-02 contained some ethene during baseline analyses, there may be dechlorinating bacteria present in those zones also. The absence of dechlorinating bacteria in some locations (e.g., as in the microcosms for MW-14S-01, MW-14S-02, MW-16S-02, MW-16S-03, MW-16S-04, and MW-16S-07) create the potential for incomplete degradation and the buildup of cDCE or vinyl chloride. Pilot testing would need to be performed to measure site-specific effectiveness prior to full-scale application.

Costs. Capital costs include installation of injection wells and monitoring wells. Because costs of drilling injection wells in rock are fairly high, the overall capital costs are moderate relative to costs for other process options. O&M costs include the price of the substrate, labor for injection, and groundwater monitoring labor and expenses. O&M costs are moderate relative to other process options.

Screening Decision. Based on the microcosm testing performed during the RI, biostimulation is a viable technology for use at OU3, especially in the vicinity of MW-14 and MW-16, where populations of dechlorinating bacteria are present at certain depth intervals. Therefore, biostimulation will be retained as a process option for consideration in alternatives assembly.

4.4.5.2. Enhanced Reductive Dechlorination via Bioaugmentation (with biostimulation)

Implementability. Bioaugmentation involves the addition of non-native organisms (typically bacteria) known to degrade the contaminants of interest. Bioaugmentation is typically performed in conjunction with biostimulation. There are several vendors that provide bacterial cultures that are known to completely biodegrade chlorinated ethenes. Bacterial cultures that degrade other COCs (e.g., PCBs) could also potentially be developed, although the time-frame for this work could be four to eight months. As with biostimulation, the main obstacle to implementing this technology is achieving uniform distribution of the bacterial cultures throughout the treatment zone. This could be accomplished by using a packer assembly for bacteria distribution at multiple depth intervals. Several commercial bacterial cultures have been applied at other sites in New Jersey, and thus have been approved for use by the NJDEP.

Effectiveness. The effectiveness of bioaugmentation is dependent on how well the applied bacterial cultures adapt and grow. This technology has been shown to be effective at many other sites; however, experience in fractured bedrock DNAPL sites is limited. A recent application of bioaugmentation in fractured rock was conducted at the former NAWC. This application involved injection of the KB-1[®] bacterial culture that contains DHE, which is known to degrade TCE to ethene, with an EVO carbon substrate. The solution containing the bacteria and the oil was injected using a recirculation approach, in which water was extracted from one well, used to make up the injection stock, and then reinjected in a different well. This process was continued until the vegetable oil was detected in the groundwater from the extracted well. In general, the results at NAWC are promising, with concentrations of chlorinated ethenes reduced by several orders of magnitude and attainment of groundwater quality standards at several monitoring locations. Most of the existing commercial bacterial strains are designed to treat chlorinated ethenes, and are not effective for treating PCBs, pesticides, and PAHs.

Costs. Capital costs include installation of injection wells and monitoring wells. Because costs of drilling injection wells in rock are fairly high, the overall capital costs are moderate relative to costs for other process options. O&M costs include the price of the substrate, price of bacterial culture, labor for injection, and groundwater monitoring labor and expenses. O&M costs are moderate relative to other process options.

Screening Decision. Based on the microcosm testing performed during the RI, bioaugmentation in conjunction with biostimulation is a viable technology for use at OU3, especially in the vicinity of locations where microcosm tests showed that dechlorinating bacteria are not present, or present at insufficient populations to achieve complete reductive dechlorination. Therefore, biostimulation will be retained as a process option for consideration in alternatives assembly.

4.4.6. In Situ Chemical Oxidation

4.4.6.1. Permanganate

Implementability. ISCO with permanganate is a proven technology that has been used at many sites (including many sites in New Jersey) to remediate chlorinated ethenes. In recent years, sodium permanganate has been applied more commonly than potassium permanganate, because potassium permanganate is regulated under the Chemical Facility Anti-Terrorism Standards (CFATS). ISCO involves installation of multiple injection wells, and typically requires a series of injection events to reduce contaminant concentrations to desired levels. There are no above-ground structures associated with ISCO (other than temporary drums or tanks used to store the permanganate during the injection events, which typically have a duration of days or weeks).

Effectiveness. The effectiveness of ISCO depends on the ability to distribute the permanganate such that it physically contacts the chlorinated ethenes in order for the oxidation reactions to occur. Effectiveness is limited by mass transfer limitation (i.e., matrix diffusion of contaminants into the rock matrix). However, permanganate has the potential for density-driven diffusion into the rock matrix to treat contaminants that are sorbed to the rock matrix. Rock oxidant demand would need to be measured prior to design of an ISCO remedy. If the rock oxidant demand is too high, then ISCO could be ineffective because much of the oxidant would be expended by unproductive reactions with rock minerals, as opposed to reacting with the chlorinated ethenes. Permanganate is not effective in treating PCBs, pesticides, or PAHs. One potential concern with the use of permanganate for DNAPL treatment is that permanganate reactions at the DNAPL interface could result in formation of a manganese dioxide "crust" around the DNAPL particles. It is unknown if this crust is temporary or if it permanently encapsulates the DNAPL. Permanganate has been applied in fractured rock with mixed success. Sites where permanganate has not been successful are located in geologic formations that impose a large rock oxidant demand, or where adequate delivery of permanganate was not achieved. The rock oxidant demand for OU3 is expected to be relatively low because the aquifer is fairly well oxidized at deeper depths (based on dissolved oxygen and ORP data) and the fraction of organic carbon in the rock matrix is quite low (LBG and Malcolm Pirnie, 2011b).

Costs. Capital costs include installation of oxidant injection wells and monitoring wells. Because costs of drilling injection wells in rock are fairly high, the overall capital costs are moderate relative to costs for other process options. O&M costs include the price of the oxidant, labor for injection, and groundwater monitoring labor and expenses. O&M costs depend on the number of injection events required to achieve desired contaminant concentration reductions. O&M costs are moderate relative to other process options.

Screening Decision. ISCO with permanganate could be applicable for treating high concentrations of chlorinated ethenes present in the vicinity of MW-14 at the former CDE facility. ISCO with permanganate is retained as a process option for consideration in alternatives assembly.

4.4.6.2. Activated Persulfate

Implementability. ISCO with activated persulfate is a proven technology that has been used at many sites (including many sites in New Jersey) to remediate chlorinated ethenes and other organic compounds. Sodium persulfate dissociates in water to form the persulfate anion ($S_2O_8^{2-}$) which, although a strong oxidant, is kinetically slow in oxidizing many organic contaminants. When catalyzed or 'activated' in the presence of high pH (e.g., via addition of sodium hydroxide [NaOH]), heat (thermal catalyzation), a ferrous salt, or hydrogen peroxide, the persulfate ion is converted to the sulfate free radical ($SO_4^{\cdot-}$). Operationally, heat activation is the most complex method to activate persulfate; therefore, high pH and peroxide activation are used most commonly. ISCO with activated persulfate involves installation of multiple injection wells, and typically requires a series of injection events to reduce contaminant concentrations to desired levels. There are no above-ground structures associated with ISCO other than temporary drums or tanks used to store the persulfate and chemical activators during the injection events, which typically have a duration of days or weeks.

Effectiveness. The effectiveness of ISCO depends on the ability to distribute the activated persulfate such that it physically contacts the organic contaminants in order for the oxidation reactions to occur. The persulfate anion and the sulfate free radical are fairly stable in the subsurface and can persist for weeks depending on subsurface conditions. The solubility of sodium persulfate at 25°C is 42 weight percent (wt%), and the density of a 40 wt% solution is 1.340 g/mL. These characteristics make persulfate an attractive oxidant for DNAPL treatment because it persists in the subsurface, can be injected at high concentrations, and will undergo density-driven and diffusive transport into low-permeability media. Persulfate may treat PCBs and pesticides if activated using heat or high pH. As with permanganate, the rock oxidant demand for persulfate would need to be measured to ensure that it is not too high. The rock oxidant demand for OU3 is expected to be relatively low because the aquifer is fairly well oxidized at deeper depths (based on dissolved oxygen and ORP data) and the fraction of organic carbon in the rock matrix is quite low (LBG and Malcolm Pirnie, 2011b). There are very few case studies of persulfate application in fractured bedrock. Anticipated performance would need to be extrapolated from case studies of activated persulfate in porous media, and/or case studies of other oxidants in fractured rock.

Costs. Capital costs include installation of oxidant injection wells and monitoring wells. Because costs of drilling injection wells in rock are fairly high, the overall capital costs are moderate relative to costs for other process options. O&M costs include the price of the oxidant and activator, labor for injection, and groundwater monitoring labor and expenses. O&M costs depend on the number of injection events required to achieve desired contaminant concentration reductions. O&M costs are moderate relative to other process options.

Screening Decision. ISCO with activated persulfate could be applicable for treating high concentrations of organic COCs present in the vicinity of MW-14 at the former CDE

facility. ISCO with activated persulfate is retained as a process option for consideration in alternatives assembly.

4.4.7. Containment using Hydraulic Control

The only process option that was retained from the initial technical feasibility screening for containment GRAs was hydraulic control using extraction wells.

Implementability. Groundwater hydraulic control using extraction wells has been used at many sites, including fractured rock settings. The water that is extracted typically requires treatment and subsequent disposal. Process options for *ex situ* groundwater treatment and discharge are discussed below. It is likely that groundwater extraction would be conducted for a long period of time because back diffusion of contaminants from the rock matrix at OU3 serves as a long-term source of contamination to the rock fractures. Permanent infrastructure may be required to treat the water that is extracted, and long-term operation of the treatment system would be needed. The treatment components are readily available.

Effectiveness. The effectiveness of hydraulic control depends on optimally placing the extraction wells and selecting groundwater extraction rates such that the hydraulic gradient is sufficiently depressed to prevent groundwater carrying contaminants from migrating to potential receptors. Extraction well placement and optimal extraction rates are often selected using a groundwater flow model.

Costs. Capital costs include drilling the extraction wells and installing pumps. Capital costs also include construction of the required *ex situ* treatment components. Typically capital costs are moderate to high, depending on the number of extraction wells required and the complexity of the treatment system. O&M costs, which depend on the complexity of the treatment train and the cost of discharge, are also typically moderate to high.

Screening Decision. Hydraulic containment using extraction wells could be applicable in the vicinity of MW-14 to prevent further migration of contaminants mass from the former CDE facility. It could also be applicable at the distal portion of the chlorinated ethene plume to maintain a TI boundary. Therefore, hydraulic containment with extraction wells will be retained as a process option for consideration in alternatives assembly.

4.4.8. Ex Situ Treatment

Table 4-2 summarizes the implementability, effectiveness, and relative costs of the presumptive *ex situ* treatment process options. USEPA's *Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites* (1996) serves as the FS technology screening step (USEPA, 1996) for the *ex situ* treatment component of a remedy. The reader is referred to Appendix C, which contains an excerpted appendix from the presumptive response guidance document with descriptions, advantages, and disadvantages of these technologies.

4.4.9. Groundwater Disposal

Three process options for discharge of treated groundwater were retained following the preliminary technical feasibility screening step. These are further evaluated below.

4.4.9.1. Discharge to Surface Water

Implementability. Under the New Jersey Pollution Discharge Elimination System (NJPDES), treated water may potentially be discharged directly to a nearby surface water body (i.e., Bound Brook, in the case of OU3). The discharge standards are typically more stringent than drinking water standards, especially for metals, which may pose ecological risks even at low concentrations. Removal of naturally occurring constituents in groundwater (e.g., arsenic) may be required to discharge the water to Bound Brook. This option may not be administratively implementable because Bound Brook contains contaminated sediment and has been designated as OU4. Discharge to Bound Brook could therefore interfere with the ongoing OU4 investigation and any potential future remediation.

Effectiveness. This is an effective and reliable means of discharging groundwater.

Costs. The costs for discharge to surface water are low to moderate depending on the degree of treatment required to meet the NJPDES requirements. Treatment for organic contaminants as well as removal of several metals would be required (see Appendix E for likely effluent requirements); therefore, costs would be closer to the moderate range.

Screening Decision. Discharge to Bound Brook is retained as a process option for consideration in alternatives assembly.

4.4.9.2. Discharge to POTW

Implementability. Treated groundwater can be discharged via a sewer system to a POTW. A temporary discharge permit was issued by the MCUA for water discharged as part of OU2 remediation activities. A new permit would be required for OU3, and the quantities of water to be discharged are anticipated to be much higher (approximately 30 to 50 gpm). Water that is discharged would have to meet the criteria specified in the TDA (see Appendix D). Because a POTW provides additional water treatment, it accepts water with higher concentrations of organic and inorganic compounds than would apply at other discharge locations.

Effectiveness. Groundwater discharge to a POTW is an effective and reliable means of discharging wastewater.

Costs. The costs depend on the discharge fees charged by MCUA. Currently, MCUA is requiring a fee of \$12,584.42 per million gallons of discharged water (MCUA, 2010). In addition, the Borough of South Plainfield currently charges \$3725 per million gallons of discharged water for sewer use fees. The Borough also charges a sewer connection fee, which is determined based on the anticipated annual average daily flow (Borough of South Plainfield, 2011).

Screening Decision. Treated groundwater discharge to MCUA is retained as a process option for consideration in alternatives assembly.

4.4.9.3. Deep Well Injection

Implementability. Extensive site assessments must be completed to determine the suitability of a site for deep well injection, and to obtain approval from regulatory authorities. At OU3, deep well injection would need to comply with New Jersey's Underground Injection Control regulations. The quality of the discharged water plays a large role in determining whether or not return of treated water to the subsurface is an appropriate discharge option. Microbial activity and/or precipitation of iron, manganese, calcium, or other metals can clog (or foul) injection wells. Fouling of injection wells occurs more frequently than clogging of extraction wells because the treated water may have higher dissolved oxygen concentrations from aeration during treatment, and this dissolved oxygen can foster microbial activity and/or metals precipitation. Given the high iron, manganese, and calcium naturally present in OU3 groundwater, there is a good potential for well fouling. Chemical treatment or well redevelopment can mitigate well fouling, but these techniques become expensive if they need to be conducted frequently. Although *ex situ* treatment could be designed to remove metals or other constituents that add to fouling, this enhanced treatment might be more expensive to construct and operate than using a different disposal option.

Effectiveness. The effectiveness of deep well injection depends on finding transmissive zones in the deep portion of the bedrock beneath OU3 to accept the fluid flow. It also depends on the degree of well fouling that is expected (see discussion above).

Costs. Moderate to high capital costs including initial site assessment and injection well installation. Low to moderate O&M costs, depending on the degree of injection well fouling.

Screening Decision. This process option is not retained because it is difficult to implement administratively, and because of the significant potential for well fouling given the high concentrations of calcium, magnesium, and iron in OU3 groundwater.

4.5. Summary of Retained Process Options

Based on the effectiveness, implementability, and cost screening described above, the following remedial process options have been retained for consideration in alternatives assembly:

- No Action
- Institutional Controls
 - Groundwater Use Restrictions
- Monitored Natural Attenuation

■ *In Situ* Treatment

- Thermal treatment via SEE, ERH, or TCH
- Bioremediation via biostimulation and/or bioaugmentation
- Chemical oxidation via permanganate or activated persulfate

■ Containment

- Hydraulic control using extraction wells

■ *Ex Situ* Treatment

- Presumptive technologies (USEPA, 1996)

■ Discharge Options

- Treated water discharge to Bound Brook or to MCUA (POTW)

5. Assembly of Remedial Alternatives

In this section, the remedial technologies and process options retained in Section 4 are used to assemble remedial alternatives for achieving the RAOs for groundwater at OU3. The alternatives developed and screened in this FS are conceptual. All characteristics of these alternatives should be considered to be approximate for the purposes of a feasibility comparison only. Specific details would be finalized during a remedial design.

5.1. Rationale for Assembly of Alternatives

Development of remedial alternatives must conform to the requirements identified in CERCLA, as amended, and to the extent possible, the NCP. CERCLA Section 121(d) requires that Superfund remedial actions attain ARARs unless specific waivers are granted, and the remedial actions must also be protective of human health and the environment. CERCLA Section 121(b) and the NCP identify the following statutory preferences when developing and evaluating remedial alternatives:

- Remedial actions involving treatment which permanently and significantly reduces the volume, toxicity, or mobility of contaminants are preferred over remedial actions not involving such treatment.
- Off-site transport and disposal of hazardous substances or contaminated materials without treatment is considered to be the least favored remedial action alternative when practical treatment technologies are available.
- Remedial actions using permanent solutions, alternative treatment technologies or resource recovery technologies shall be assessed.
- Use engineering controls (i.e., containment) for wastes that pose a relatively low long-term threat or where treatment is impracticable.
- Use a combination of methods where appropriate.
- Use institutional controls, as appropriate, for short- and long-term management to prevent or limit exposure.

The following assumptions have been made in developing the remedial alternatives for OU3:

- It is assumed that a waiver of ARARs will be granted within the TI Zone presented on Figure 3-1.
- It is assumed that there are no on-going contaminant releases from overburden soil because remediation activities at OU2 are nearing completion at the time of the preparation of this FS and are expected to be completed during in late 2011.

- It is assumed that all of the remedial alternatives have a time frame of 30 years, in accordance with CERCLA guidance for costing procedures. The actual duration of the proposed remedies would be based on monitoring results. However, field results, combined with numerical modeling, indicate that the time for these types of contaminated bedrock groundwater sites to become 'clean' is many decades to centuries or longer, due to long time scales for back diffusion, and several orders of magnitude differences between initial concentrations (solubility) and typical PRGs (i.e., MCLs). The 30 year technical analyses and cost evaluations are also presented in the FS for consistency between alternatives.
- Remedial alternatives are assembled primarily based on their ability to mitigate the chlorinated ethenes in the bedrock groundwater.
- Based on the results of the BHHRA (LBG and Malcolm Pirnie 2011a), there is a potential for adverse cancer and non-cancer health effects from exposure to groundwater.
- It is assumed that site conditions that will be in place following the conclusion of ongoing remedial activities within the former CDE facility in late 2011 will remain the same during the implementation of the remedial alternatives
- The potential for groundwater constituents to migrate to surface water and sediments in Bound Brook is being evaluated as part of OU4. Remedial alternatives to address groundwater discharge to Bound Brook, if needed, will be evaluated in the OU4 FS.

5.2. Development of Alternatives

Based on the rationale presented above, and the technology and process options that have been retained after screening, the following six alternatives are proposed for the groundwater at OU3:

- Alternative 1: No Action
- Alternative 2: Monitored Natural Attenuation (MNA) with Institutional Controls (ICs)
- Alternative 3: Source Area Hydraulic Control at the former CDE facility using Groundwater Extraction Wells (includes MNA and ICs)
- Alternative 4: Source Area Thermal Treatment (includes MNA and ICs) at the former CDE facility
- Alternative 5: Source Area In Situ Chemical Oxidation (includes MNA and ICs) at the former CDE facility
- Alternative 6: Source Area In Situ Bioremediation (includes MNA and ICs) at the former CDE facility

Each alternative is intended to represent a conceptual approach to remedial action rather than a specific design. The "source area" differs somewhat for each alternative, and is

defined in the description for each alternative provided below. The alternatives were evaluated using MODFLOW, a three-dimensional (3D) finite difference flow model, and FRACTRAN, a numerical two-dimensional (2D) DFN model. The model results that support the alternative descriptions are presented in this section.

5.3. Alternative 1 – No Action

Alternative 1 was developed from the NCP provision that requires consideration of a limited or no action response to serve as a baseline for evaluating other remedial alternatives.

The No Action response does not include any containment, removal, disposal, or treatment of contaminated groundwater. In accordance with OSWER Directive 9283.1-33 (June, 2009), it also does not include new or existing institutional controls. Existing monitoring wells would remain in place. Any improvement of groundwater quality would be through natural attenuation including biodegradation, adsorption or diffusion into the rock matrix, dispersion, and dilution.

Because hazardous contaminants remain at the Site under this alternative, five-year remedy reviews are required under CERCLA Section 121(c). Therefore, groundwater monitoring is required under this alternative to provide data to prepare the five-year remedy reviews. It is assumed that no new wells will be installed, and that annual monitoring would be performed at one up-gradient monitoring location (ERT-1), two locations on the former CDE facility (MW-14S/D and MW-16), and two down-gradient monitoring locations (MW-20 and MW-23).

Much of the chlorinated ethene contaminant mass present at OU3 was released to the subsurface decades ago (CDE was operational from 1936 to 1962). Over time, contaminant mass was transferred from the bedrock fractures to the rock matrix via matrix diffusion. As a result, much of the contaminant mass at OU3 currently resides in the rock matrix, as demonstrated by results of rock pore water analyses performed during the RI (see Section 2). Parker et al. (2010) performed a study of eight sites similar to CDE OU3, where DNAPL has been present for decades in fractured sedimentary rock. The field results, combined with numerical modeling, indicate that the time for these types of sites to become 'clean' is many decades to centuries or longer, due to long time scales for back diffusion, and several orders of magnitude differences between initial concentrations (solubility) and typical PRGs (i.e., MCLs).

5.4. Alternative 2 – Monitored Natural Attenuation with Institutional Controls

Alternative 2 has been developed to limit receptor exposure to contaminated groundwater, while demonstrating reduction of contaminant concentrations by natural processes. Alternative 2 relies on natural mechanisms including dispersion, diffusion, dilution, adsorption, and biodegradation to reduce concentrations of contaminants in

groundwater. Comprehensive monitoring is a required component to evaluate and verify the progress of MNA, as is a contingency plan that defines the appropriate response actions(s) should MNA not perform as expected. Institutional controls would be implemented to prevent or reduce exposure to hazardous substances. A groundwater CEA would be established in accordance with New Jersey regulations.

Alternative 2 differs from Alternative 1 in that groundwater monitoring is much more comprehensive than for Alternative 1, and is conducted to verify and track the progress of MNA, while comparing it to predicted restoration rates. Monitoring results would be evaluated and reported in annual monitoring reports. OSWER Directive 9200.4-17P (USEPA, 1999) requires that “MNA will be an appropriate remediation method only where its use will be protective of human health and the environment and it will be capable of achieving site-specific remediation objectives *within a time frame that is reasonable compared to other alternatives*”. As discussed above for Alternative 1, based on experience at other sites where DNAPL was released to fractured sedimentary rock, and where much of the contaminant mass now resides in the rock matrix, remediation time frames are on the order of decades or longer.

For this alternative, it is assumed that the existing monitoring wells used for the RI (see Table 2-1) as well as four new monitoring wells with fLUTE multi-level systems will be used as the MNA network. The four additional monitoring wells would be installed at the edges of the TI zone to monitor contaminant concentrations at the distal portions of the plume. The duration of the MNA program is assumed to be 30 years. Initially, the wells would be sampled quarterly for the first two years, to capture seasonal changes in COC concentrations (samples would be analyzed for VOCs and MNA parameters quarterly, and for PCBs, SVOCs, metals, and pesticides semi-annually). Also, NJDEP recommends quarterly sampling for the first two years of an MNA program. After two years of quarterly monitoring, the data would be reviewed to determine whether sampling frequency should be reduced or eliminated for specific wells. It is assumed that for years 3 to 5, sampling would be performed on a semi-annual basis, for years 6 to 15 sampling would be performed annually, and for years 16 to 30, sampling would be performed once every two years.

Any well in the MNA network that becomes damaged, or is required to be removed due to remedial action or other activities, would be replaced or repaired, as needed. Because hazardous contaminants remain at the Site under this alternative, five-year remedy reviews are required under CERCLA Section 121(c).

5.5. Alternatives 3 – Source Area Hydraulic Control with MNA and ICs

This alternative involves controlling the discharge of contaminated groundwater from the source area (defined as the former CDE facility boundary for this alternative), thereby reducing contaminant mass flux from the former CDE facility to down gradient areas/receptors. Alternative 3 also includes MNA and ICs, as discussed in Alternative 2.

Hydraulic control of groundwater would be accomplished by extracting contaminated groundwater at a rate of approximately 40 gpm via two vertical extraction wells, each approximately 130 feet deep, and located at either end of the former CDE facility (i.e., 20 gpm extraction rate at each well). The groundwater extraction well depths and total flow rate were selected based on preliminary results of a MODFLOW groundwater extraction simulation. This alternative assumes that an on-Site groundwater treatment system would be needed to treat the extracted groundwater. Two discharge options are evaluated for treated groundwater: discharge to MCUA (Alternative 3a) and discharge to Bound Brook (Alternative 3b). Although the final technology selection for an *ex situ* groundwater treatment system will be deferred to the remedial design (RD) phase, representative process options have been selected to assemble a likely treatment train for cost estimating purposes in the FS. The groundwater treatment system is assumed to include the following processes:

- Removal of DNAPL (i.e., oil-water separation)
- Acidification (to control scaling due to high calcium and magnesium concentrations in the groundwater at OU3)
- Sediment Filtration
- Chemical / Ultraviolet (UV) oxidation to treat organics (chlorinated ethenes and ethanes, benzene compounds, PCBs, pesticides, and dioxins/furans)
- Catalytic Filter (required for metals removal for Alternative 3b only)
- Effluent polishing (liquid-phase granular activated carbon)
- Neutralization
- Discharge to MCUA or to Bound Brook

Hydraulic control through groundwater extraction removes only the contaminant mass that is present in the bedrock fractures within the area of hydraulic influence. The time frame for back diffusion of the contaminant mass (primarily TCE and cis-1,2-DCE) residing in the rock matrix back to the fractures is on the order of decades or longer. Therefore, it is expected that groundwater extraction (and treatment) to maintain hydraulic control/capture at the former CDE facility may be required for decades or longer, assuming that it would continue while concentrations of contaminants exceed PRGs. However, as discussed in Section 5.1, the cost evaluation of this alternative assumes a duration of 30 years. It is assumed that the MNA program, as discussed in Alternative 2, will be sufficient to monitor the performance of the hydraulic control remedy as well as the progress of MNA.

Pilot testing may be required to refine the design of the full-scale treatment system and to ensure that MCUA's effluent discharge limits (Alternative 3a) or NJDEP's effluent concentrations for FW-2 streams (Alternative 3b) are met (see Appendices D and E). Because the system would need to be operated for many years, the RD would need to consider O&M requirements for the various treatment system components, and to

optimize the design based on minimizing O&M. The building housing all of the treatment components, as well as the piping connecting the various components of the system, would need to be designed to operate for an extended period of time (likely decades). Contaminant concentrations may fluctuate widely over time. Therefore, the RD for this system would need to be flexible enough to allow for use of different technologies, as appropriate, over time (for instance, if concentrations of chlorinated ethene and PCBs decreased markedly, then it may be more cost effective to use granular activated carbon for organics treatment rather than chemical/UV oxidation).

5.6. Alternative 4 – Source Area Thermal Treatment with MNA and ICs

The conceptual design for Alternative 4 involves thermal treatment using two thermal treatment process options: TCH (also known as ISTD) and SEE. The goal is to remove contaminant mass from the source area located at the former CDE facility to reduce contaminant mass flux from the former CDE facility. Alternative 4 includes implementation of institutional controls as well as detailed monitoring for natural attenuation, as discussed for Alternative 2.

For this alternative, the source area is defined as a circular area centered on monitoring well MW-14S, with a radius of 120 feet (see Figure 5-2). The 120-foot radius was selected because it is approximately one-half of the distance between MW-14S and MW-12S, which is the closest downgradient monitoring point from MW-14S where no DNAPL is expected to be present based on groundwater sample analyses performed during the RI. The target treatment depth is 15 feet to 65 feet bgs. The shallow limit of the treatment depth is 15 feet bgs because this is the average depth to the water table. The deep limit of the treatment depth was selected based on the rock coring VOC results, groundwater analytical data, and fracture mapping at MW-14S and MW-14D. These data indicate that a major fracture zone exists at approximately 65 feet bgs. This fracture zone is a major contaminant mass transport network and the amount of contaminant mass entrained in the rock and also in the fractures below this zone drops off significantly compared to the amount of contaminant mass present above the fracture zone.

TCH was selected for use as a process option because this technology has been used at two fractured rock sites containing DNAPL, including a site in New Jersey in a silt and mudstone geology. The TCH heater elements can be accommodated in three- to four-inch diameter boreholes while, due to the depth of treatment, ERH electrodes would need to be stacked in 10- to 12-inch diameter boreholes, resulting in much higher drilling and waste disposal costs. TCH relies on using electricity applied to heater borings to generate very high temperatures (i.e., $>500^{\circ}\text{C}$) at the heater well. The heat migrates away from the heater borings by a combination of thermal conduction (driven by a temperature gradient) and convection (migration of steam produced by boiling groundwater). The rock fractures are major pathways for the generated vapor to escape and be captured by a vacuum extraction system. In a typical fractured rock application, every heater is supplied with a vapor recovery point, so the entire treatment zone is kept under a vacuum

to minimize transport of contaminants out of the treatment zone. The conceptual design for thermal treatment at OU3 involves the use of TCH to heat the bedrock at a depth of 15 to 50 feet bgs (Zone 1). The zone from 50 – 65 feet bgs (Zone 2) would be treated using SEE. The use of steam at the bottom of the thermal treatment area would create a “hot floor” to provide a barrier to vertical migration of contaminants. Also, SEE is better suited to zones of high groundwater flow (i.e., the transmissive fractures that occur at about 65 feet bgs in the vicinity of MW-14) than TCH. The target temperature for the aquifer is 100°C. At this temperature, dissolved phase and non-aqueous phase chlorinated ethenes would be vaporized and removed via soil vapor extraction (SVE) points and multiphase extraction (MPE) wells. Although a portion of the PCBs, pesticides, and SVOCs would likely also be removed, higher temperatures would be needed to obtain reliable removal for these compounds. These high temperatures are only attainable if the aquifer is dewatered, which is not feasible given the highly transmissive weathered rock zone at 65 feet bgs. The fate of dissolved and adsorbed contaminant mass located within the rock matrix is uncertain. However, it is assumed that at least a portion of the contaminant mass within the rock matrix would be volatilized and would back diffuse and be captured by the thermal treatment system. Additional rock core testing could be performed to gauge the effectiveness of the thermal treatment in removing mass from the rock matrix.

The conceptual thermal treatment design provided by TerraTherm, Inc. (included in Appendix F) includes the following major components:

- Installation of 279 heater wells, 82 vertical SVE wells and 82 MPE wells to treat Zone 1. The heater wells would be installed at a 15-foot spacing.
- Installation of 85 steam injection wells and 28 MPE wells in Zone 2. The steam wells would be installed at a 30-foot spacing.
- Installation of 51 temperature monitoring points over the vertical treatment area.
- Installation of 13 pressure monitoring points in the 0 to 15 feet bgs unsaturated zone.
- If needed, a vapor cap would be installed to extend slightly beyond the boundaries of the treatment area.
- Thermal oxidation is assumed for use as an above-ground vapor treatment technology, and liquid GAC is included for the liquid treatment (see Appendix F for schematics of the proposed effluent treatment system).

The total operating time for thermal remediation is estimated to be 145 days, or just under five months. Including time required to drill the various wells and heating points, and time to demobilize, the duration of thermal treatment would be approximately seven to eight months. After the completion of thermal treatment, detailed MNA monitoring would be performed as described in Alternative 2.

5.7. Alternative 5 – Source Area In Situ Chemical Oxidation with MNA and ICs

The conceptual design for Alternative 5 involves ISCO at the former CDE facility with high pH-activated sodium persulfate. The goal is to remove contaminant mass from the source area located at the former CDE facility to reduce contaminant mass flux from the former CDE facility. Alternative 5 includes implementation of institutional controls as well as detailed monitoring for natural attenuation, as discussed for Alternative 2.

ISCO with permanganate and ISCO with sodium persulfate were both retained as process options following the technology screening described in Section 4. Sodium persulfate has been selected as the representative process option for the CDE OU3 FS for the following reasons:

- Persulfate's ability to degrade a broad range of contaminant types (including PCBs, pesticides, and SVOCs)
- Permanganate may form a manganese dioxide surface 'crust' as it reacts with DNAPL; this crust may then inhibit further chemical oxidation treatment. Also, permanganate is ineffective for treating PCBs, pesticides, chlorinated ethanes, and PAHs.

High pH activation of persulfate has been selected as the process option for this alternative. This is the technique typically recommended by FMC, the manufacturer of sodium persulfate in the United States. Also, high pH activated persulfate has the ability to treat a wider range of contaminant types (particularly PCBs) than hydrogen peroxide-activated persulfate, and is operationally less complex than heat activated persulfate. Persulfate is hydrophilic and thus will not significantly partition into oil-like phases. As a result, oxidation will take place at the surface of NAPL only or in the dissolved phase remote from the NAPL surface, resulting in a slow rate of NAPL destruction. Alkalinity is known to provide detergency through solubilization of oils and saponification of fatty acid type compounds. As a result, addition of high pH modifiers, such as NaOH, aid in the dissolution of NAPLs and enhance contact with the oxidant.

For Alternative 5, the source area is defined in the same manner as for Alternative 4 (i.e., as a circular area centered on monitoring well MW-14S with a radius of 120 feet, as shown on Figure 5-2). The target treatment depth is 20 feet to 65 feet bgs, with two depth intervals to be targeted for ISCO injections: 20-40 feet bgs, and 45-65 feet bgs. It is assumed that the well spacing for persulfate injection points will be 40 feet (i.e., 20 foot injection radius of influence; see Figure 5-3). This is a fairly large spacing; however, the rock is fairly weathered in the interval from 20-65 feet bgs, and therefore a high radius of influence would be expected (a pilot study is included as part of this alternative to refine the injection radius of influence). The well spacing could potentially be increased up to 80 or 100 feet for a continuous recirculation system in which oxidant solution is injected up-gradient of the target zone and then extracted down-gradient of the target zone, re-amended with additional oxidant/activator, and reinjected. The

recirculation approach requires more complicated and costly above-ground infrastructure, and oxidant recirculation systems at other sites have experienced problems involving fouling of injection wells. For purposes of the FS, batch oxidant injections will be assumed; however, recirculation wells could be considered if ISCO were to be implemented at the Site. Alternative 5 includes detailed monitoring within the treatment area to evaluate ISCO effectiveness.

The design injection concentration of persulfate is assumed to be 25 weight percent (wt%). This is a fairly high concentration, but was selected due to the large oxidant demand imposed by TCE DNAPL and high PCB concentrations at MW-14, the fact that persulfate solution density increases with concentration (high density is desirable when treating DNAPLs), and that the fracture pore volume is quite small, limiting the amount of fluid that can be injected in the treatment area. For alkaline activation of persulfate, the pH of the aquifer will need to be maintained between 10.5 and 12. The NaOH demand arises from two sources: (1) soil and groundwater acidity; and (2) the generation of acid formed during the decomposition of persulfate. In order to neutralize the persulfate-generated acid, 2 moles of NaOH must be added per mole of persulfate. This equates to 0.33 pound (lb) of NaOH required per lb of persulfate. A soil (or, for OU3, a powdered rock) titration is typically required to determine the amount of NaOH needed to raise the pH of site soil and groundwater to between 10.5 and 12. These data are not available for OU3; therefore, it was assumed that an additional 20% of NaOH is required beyond the amount needed to neutralize the persulfate-generated acid. It is recommended that the NaOH solution be applied either immediately prior to or after the application of persulfate (i.e., not batched in one tank for simultaneous injection). This is because at the dosage of persulfate proposed in this conceptual design, severe exothermic reactions may occur when these reagents are mixed together, which could result in steam eruptions, loss of product containment, and damage to equipment. These exothermic reactions are beneficial in the subsurface, as they will serve to create heat, which leads to formation of persulfate radicals. Also, mixing the NaOH and persulfate together prior to injection results in faster decomposition of the persulfate before it is applied in the subsurface.

For purposes of the cost estimate, it was assumed that for each injection event, 0.5 pore volumes would be displaced with persulfate (the NaOH volume was not included in the pore volume estimate). In practice, the number of injection events would be dependent on performance results, which are a function of the ability of the oxidant to contact the contaminants. It is assumed that persulfate injections would be performed quarterly for a period of five years. This will result in a total of 10 pore volumes of oxidant injection over the ISCO treatment program. It is expected that the ISCO applications will treat most of the contaminant mass present in the rock fractures, but only a portion of contaminant mass present in the rock matrix. Therefore, after the completion of ISCO treatment, detailed MNA monitoring would be performed as described in Alternative 2.

5.8. Alternative 6 – Source Area In Situ Bioremediation with MNA and ICs

The conceptual design for Alternative 6 involves *in situ* bioremediation via enhanced anaerobic biodegradation at the former CDE facility. Bench microcosm studies performed during the RI demonstrated that, under optimal conditions for anaerobic biodegradation (i.e., addition of carbon substrate and nutrients), complete transformation of TCE to ethene occurred in groundwater samples collected from MW-14D-01, MW-14S-04, MW-16-05, and MW-16-07 (BCI, 2010). The complete dechlorination of TCE to ethene indicates that dechlorinating bacteria are naturally present at these locations. Also, it was hypothesized that, because samples from MW-14S-01 and MW-14S-02 contained some ethene during baseline analyses, there may be dechlorinating bacteria present in those zones also.

The conditions required for anaerobic biodegradation of chlorinated ethenes may be created in the field by adding carbon substrates that are fermented by a wide variety of organisms, producing hydrogen gas. The hydrogen gas may then be used by dechlorinating bacteria as an electron donor in the reductive dechlorination of chlorinated ethenes. There are many organic substrates that can be naturally degraded and fermented in the subsurface to produce hydrogen. The substrates most commonly used to enhance anaerobic biodegradation of chlorinated ethenes include lactate, molasses, Hydrogen Release Compound (HRC[®] - available in several formulations), and vegetable oils (neat and emulsified). These substrates may be classified as soluble substrates (e.g., lactate and molasses), viscous fluids (e.g., HRC[®] and neat vegetable oils), low viscosity fluids (e.g., vegetable oil emulsions), and solid substrates (e.g., mulch and compost) (AFCEE et al., 2004). The type of substrate most suited for use at OU3 depends on the selected method of substrate application. For batch substrate applications, slow-release viscous fluid substrates, designed to be long-lasting and relatively immobile in the subsurface, are most suitable to minimize advective loss of the substrate. For a continuous recirculation application (i.e., substrate is injected up-gradient of the target zone, groundwater is then extracted down-gradient of the target zone, re-amended with additional substrate, and reinjected), a soluble substrate that travels with advective flow offers the greatest potential for uniform distribution.

For purposes of the FS, batch substrate injections will be assumed. The recirculation approach requires more complicated and costly above-ground infrastructure, and operational difficulties due to biofouling are common. The selected carbon substrate for the FS evaluation is EVO, a viscous material composed primarily of soybean oil (some formulations include lactate also) capable of releasing lactic acid for periods exceeding three years. For Alternative 6, the source area is defined in the same manner as for Alternatives 4 and 5 (i.e., as a circular area centered on monitoring well MW-14S with a radius of 120 feet, as shown on Figure 5-2). As for Alternatives 4 and 5, the target treatment depth is 15 feet to 65 feet bgs. It is assumed that the well spacing for EVO injection points will be 35 feet (i.e., 17.5 foot injection radius of influence). This well

spacing is slightly closer than the spacing assumed for the ISCO remedy because of the higher viscosity of EVO. Although the bench microcosm studies indicated the presence of dechlorinating bacteria, bioaugmentation (i.e., injection of a non-native or enriched microbial culture known to degrade targeted compounds) is recommended as geochemical data indicates that sufficient quantities of anaerobic dechlorinating bacteria may not currently be present in all areas of the treatment zone.

The remediation time frame is determined by the longevity of the EVO in the subsurface and the time required to treat the groundwater. Although EVO is able to release lactate for up to several years, it is subject to advective fracture flow dynamics, which may transport it away from the treatment area. Therefore, it is assumed that EVO injections will be performed annually for ten years. The EVO applications will treat most of the contaminant mass present in the rock fractures but only a fraction of contaminant mass present in the rock matrix (through back-diffusion to the fractures). Therefore, after the completion of bioremediation treatment, detailed MNA monitoring would be performed for a timeframe similar to that described in Alternative 2 (i.e., on the order of decades or centuries).

6. Detailed Evaluation of Remedial Alternatives

The objective of the detailed analysis of alternatives is to provide adequate information for each alternative to facilitate the selection of remedial actions for implementation at the Site. In this section, each of the alternatives developed in Section 5 are assessed under the evaluation criteria specified in the NCP. The detailed analysis consists of the following components:

- A detailed evaluation of each remedial alternative in relation to the two “threshold” criteria and five “balancing” criteria listed in the NCP. The two “modifying” criteria (i.e., state acceptance and community acceptance of the remedial alternatives) are evaluated after the FS has been completed, in USEPA’s Responsiveness Summary to the Proposed Plan.
- A comparative analysis to evaluate the relative performance of each alternative in relation to each other and the evaluation criteria.

6.1. Evaluation Criteria

Provisions of the NCP require that each alternative be evaluated under nine criteria listed in 40 CFR 300.430(e)(9). The nine evaluation criteria are described below.

6.1.1. Threshold Criteria

To be eligible for selection, an alternative must meet the two threshold criteria described below, or in the case of ARARs, must justify why a waiver is appropriate.

Overall Protection of Human Health and the Environment. Evaluation of the overall protectiveness of an alternative focuses on whether the alternative provides adequate protection and describes how risks associated with the potential site-specific exposure pathways are mitigated through treatment, engineering, and /or institutional controls. Overall protection of human health and the environment draws on the assessments of other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Compliance with ARARs. This evaluation criterion is used to assess whether a remedial alternative will satisfy the federal and state ARARs identified in Section 3.2 of this FS. As discussed previously, a TI waiver from groundwater ARARs has been granted for OU3, and is detailed in a separate TI evaluation report.

6.1.2. Balancing Criteria

The five “balancing” criteria are the primary criteria upon which the detailed evaluation and comparative analysis of alternatives is based. The analysis of these criteria is

performed in sufficient detail to understand the significant aspects of each alternative and to identify the uncertainties associated with the evaluation.

Long-Term Effectiveness and Permanence. The long-term effectiveness and permanence criterion addresses the results of a remedial action in terms of the risk remaining at the site after response objectives have been met. Consideration should be given to residual risk remaining from treatment of residuals and/or untreated constituents at the conclusion of remedial activities and the requirement of a five-year review. In addition, the evaluation should include an assessment of the adequacy and reliability of remedial controls, if any, that are used to manage treatment of residues or untreated constituents remaining at the Site. Issues for evaluation are type and degree of long-term management and operations and maintenance (O&M) functions.

Reduction in Mobility, Toxicity, or Volume through Treatment. This criterion addresses the statutory preference for selecting remedial actions that employ treatment technologies that permanently and significantly reduce toxicity, mobility, or volume of the hazardous substances.

Short-Term Effectiveness. This criterion addresses the effects of the remedial alternative on human health and the environment during the construction, implementation, and operational phases of remedial action until response objectives have been met. Consideration is given to protection of the community and workers during construction phases and the effectiveness and reliability of available worker protective measures. Other considerations include the potential short-term adverse environmental impacts that may result from the construction and implementation of an alternative and the time required to complete construction, implementation, and O&M activities to achieve remedial objectives. Estimated remedial times are based on the time required to remediate sites with similar COCs and conditions, COC degradation data, and professional judgment.

Implementability. The implementability criterion addresses the technical and administrative feasibility of implementing an alternative. Factors considered in this evaluation include the following:

- Technical feasibility, including the technical difficulties and unknowns associated with the construction and operation of a technology, the reliability of the technology, the ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy.
- Administrative feasibility, including the activities needed to coordinate with other agencies and the ability and time required to obtain any necessary approvals and permits from the other agencies (e.g., for off-site actions).
- Availability of services and materials, including the availability of adequate off-site treatment, storage capacity, and disposal services; the availability of necessary equipment and specialists, and provisions to ensure any necessary additional

resources; the availability of services and materials; and the availability of prospective technologies.

Cost. Costs for CERCLA evaluations are divided into two principal categories: capital costs and annual O&M costs. Consistent with the RI/FS guidance (USEPA, 1988), cost estimates performed during the feasibility study stage are expected to provide an accuracy of -30 percent to +50 percent. Capital costs and O&M costs have been estimated for all of the remedial alternatives. Cost tables and a summary of major cost assumptions are on **Tables 6-1 to 6-7**.

Capital Costs. Capital costs are defined as those expenditures required when initiating and implementing a remedial action. These are short-term costs and are exclusive of costs required to maintain the action throughout the project lifetime. These direct costs include construction costs and expenditures for equipment, labor, disposal, permits, start-up, and materials required during the remedial action installation. Bid and scope contingencies are applied to the remedial alternatives, as appropriate, in accordance with USEPA cost estimating guidance (USEPA, 2000). The bid contingency accounts for factors that tend to increase costs associated with constructing a given project scope, such as economic/bidding climate, contractor's uncertainty regarding liability and insurance on environmental cleanup sites, adverse weather, and geotechnical unknowns. The bid contingency also covers changes during final design and implementation. Scope contingencies include provisions for inherent uncertainties such as expansion of the extent of remediation needed and regulatory or policy changes that may affect the initial assumptions. The costs for engineering design, construction management, and project management are also included in the capital costs.

O&M Costs. Annual O&M costs are associated with measures required to maintain the effectiveness of response actions. These costs include labor, monitoring, materials, utilities, residuals disposal, administrative support, and Site reviews. The cost estimates generated for this analysis are based on an O&M period of 30 years. However, a longer timeframe may apply for some of the remedial alternatives.

Present Worth Analysis. In order to compare costs for alternatives that have different implementation time frames, the present worth for each alternative was calculated. A discount rate of **2.3 percent** is used for the present worth calculation. This discount rate is obtained from the Office of Management and Budget (OMB) Circular A-94, Guidelines and Discount Rates for Benefit Cost Analysis of Federal Programs (December 2010).

6.1.3. Modifying Criteria

The modifying criteria will not be addressed in this FS, but are mentioned below in the interest of explaining the remedy selection process.

State Acceptance. This criterion provides the state – in this case, the State of New Jersey – with the opportunity to assess any technical or administrative issues and

concerns regarding each of the alternatives. State acceptance is not addressed in this document, but will be addressed in the proposed plan and the ROD.

Community Acceptance. Issues and concerns the public may have regarding each of the alternatives fall into this criterion. As with state acceptance, this criterion will be addressed in the ROD once comments on the FS and proposed plan have been received.

6.2. Detailed Analysis of Individual Alternatives

The following sections present detailed analyses of the six proposed alternatives. Cost summaries are discussed in this section and are presented on Tables 6-1 to 6-6 for alternatives 1 to 6, respectively. Table 6-7 presents a summary of the costs of all of the remedial alternatives. As part of the RI/FS, MODFLOW, a three-dimensional (3D) finite difference flow model, and FRACTRAN, a numerical two-dimensional (2D) DFN model, were constructed using OU3 characterization data collected during the RI. These models have been used as tools to evaluate the effectiveness of the alternatives. The results of the model alternative analyses are summarized, where applicable, in the alternatives evaluations.

6.2.1. Alternative 1: No Further Action

In this alternative, no groundwater remediation systems would be installed or operated, no institutional controls would be implemented, and only cursory monitoring would be performed to enable preparation of CERCLA five-year reviews. Any improvement in water quality would be through natural attenuation of the contaminants by biodegradation, adsorption to or diffusion into the rock matrix, dispersion, and dilution.

6.2.1.1. Overall Protection of Human Health and the Environment

This alternative would not be effective in protecting human health and the environment. It would provide no administrative system to control the use of contaminated groundwater or monitor concentrations to determine significant changes in plume concentrations and configuration.

6.2.1.2. Compliance with ARARs

There would be no means to monitor the TI zone; therefore, it is unknown whether potential receptors would be protected, and RAOs would not be met.

6.2.1.3. Long-Term Effectiveness and Permanence

This alternative would not achieve long-term effectiveness or permanence. There would be no use restrictions in place to prevent exposure to contaminated groundwater. The effectiveness of natural attenuation processes would be unknown without an adequate monitoring network, and there would be no means to monitor the TI zone.

6.2.1.4. Reduction of Toxicity, Mobility, and Volume

This evaluation criterion refers to a reduction in toxicity, mobility, or volume through recovery or treatment. There is no treatment, so the statutory preference for treatment is

not a component of this alternative. There would be no documented reduction in toxicity, mobility, or volume of contaminants.

6.2.1.5. Short-Term Effectiveness

There would be a low risk to workers during groundwater sampling activities. Since only sampling activities would take place under this alternative, there would be low risk to the community, as monitoring wells would be capped and locked, purge water would be contained and properly disposed, and traffic controls would be maintained during sampling for any wells installed in or near roadways.

6.2.1.6. Implementability

There would be no technology or engineering controls to implement under this alternative. No permits are required, and there are no administrative controls to implement. A minimal monitoring program would be performed annually (collection of groundwater from five monitoring wells with multilevel systems), and five-year CERCLA reviews would be prepared.

6.2.1.7. Cost

Detailed costs are shown in Table 6-1. Capital costs for this alternative are estimated to be \$33,000, which is the cost of preparing a monitoring work plan. The present worth costs for 30 years of O&M (which includes annual monitoring and submission of CERCLA review every five years) is \$2,093,000. The total present worth of this alternative is estimated at \$2,126,000.

6.2.2. Alternative 2: Monitored Natural Attenuation with Institutional Controls

This alternative would consist of a detailed groundwater monitoring program to measure COCs and MNA parameters, well restrictions in a groundwater CEA, reporting, and maintenance of the monitoring well system. This alternative was developed to limit public exposure to contaminated groundwater and to document the progress of natural attenuation of COCs at OU3.

6.2.2.1. Overall Protection of Human Health and the Environment

Under this alternative, potential human exposure to groundwater would be controlled by the establishment of a groundwater CEA. The CEA provides an institutional control through a notice that there is groundwater contamination in the area. It also gives the State the authority to restrict the installation of wells and the use of groundwater in the CEA. Monitoring of groundwater would be performed to document the extent and levels of groundwater contamination within the CEA and within the TI zone, and to verify that contaminants do not migrate beyond these areas (it is anticipated that the boundaries of the CEA and TI zone will be similar). Natural attenuation parameters would be analyzed to document the conditions for natural degradation.

6.2.2.2. Compliance with ARARs

Groundwater ARARs have been waived for the TI zone. Concentrations of COCs would decrease through time within the TI zone. Estimated time frames to achieve ARARs in the TI zone are discussed in more detail for the long-term effectiveness criterion.

6.2.2.3. Long-Term Effectiveness and Permanence

This alternative provides a robust monitoring system to document groundwater quality and natural attenuation of contaminants through rock matrix diffusion processes, degradation, retardation, dispersion, adsorption, and mineral precipitation. Groundwater use would be controlled using well restrictions in a groundwater CEA. The long-term effectiveness of the natural attenuation processes was evaluated using the FRACTRAN model (see Appendix A). To model the MNA alternative, continued input of chlorinated ethene mass at 10% of solubility was assumed (i.e., no source reduction). The model results indicate that chlorinated ethenes will persist at concentrations exceeding ARARs for very long time periods (i.e., beyond 150 years). However, the rate of plume front migration is very slow due to the effects of matrix diffusion. Therefore, this remedy could be effective for preventing contaminant migration beyond the TI zone.

6.2.2.4. Reduction of Toxicity, Mobility, and Volume

There is no active recovery or treatment for groundwater, so the statutory preference for treatment is not a component of this remedy. However, it is expected that, over time, there would be reductions in COC toxicity, mobility, and volume due to natural attenuation processes (primarily matrix diffusion). The degree of expected attenuation and the time-frames for attenuation are discussed above for the long-term effectiveness criterion.

6.2.2.5. Short-Term Effectiveness

Since the implementation of this remedy would involve the drilling and installation of four additional deep monitoring wells (average depth of 500 feet), there would be risks to workers commensurate with these types of activities. There would be a low risk to workers during groundwater sampling activities. Since only sampling activities would take place under this alternative, there would be low risk to the community, since the monitoring wells would be capped and locked, all sampling and purge water would be contained and properly disposed, and traffic controls would be maintained during sampling for any wells installed in or near roadways.

6.2.2.6. Implementability

This alternative would be straightforward to implement. Monitoring well installation and maintenance, multi-level sampling system installation, and groundwater sampling are well-known technologies and procedures. Services and materials would be readily available to install the monitoring wells and multi-level monitoring systems.

6.2.2.7. Cost

Detailed costs are shown in Table 6-2. Capital costs for this alternative are estimated to be \$1,090,000. The present worth costs for 30 years of MNA is estimated at \$8,080,000. The total present worth of this alternative is \$9,170,000.

6.2.3. Alternative 3: Source Area Hydraulic Control with MNA and ICs

Alternative 3 controls the discharge of contaminated groundwater from the source area (defined as the former CDE facility boundary for this alternative), thereby reducing contaminant mass discharge from the source area. Groundwater would be pumped from the source area, treated, and discharged. For Alternative 3a, treated water would be discharged to the MCUA; for Alternative 3b, treated water would be discharged to Bound Brook. Alternatives 3a and 3b also include MNA and ICs, as discussed in Alternative 2.

6.2.3.1. Overall Protection of Human Health and the Environment

Under this alternative, potential human exposure to groundwater would be controlled by the establishment of a groundwater CEA. Since it relies on advective transport of COCs, the withdrawal of groundwater from the source area will only result in the removal of minimal contaminant mass and COC concentration reductions; however, it will effect the reduction of contaminant mass discharge from the source area by reducing the volume of groundwater leaving that area. Monitoring of groundwater concentrations immediately downgradient from the treatment area would document the performance of the hydraulic control. Monitoring of groundwater would also be performed to document the extent and levels of groundwater contamination within the CEA and within the TI zone, and to verify that contaminants do not migrate beyond these areas. Natural attenuation parameters would be analyzed to document the conditions for natural degradation.

6.2.3.2. Compliance with ARARs

Groundwater numerical concentration ARARs have been waived for the TI zone. Estimated time frames to achieve ARARs in the TI zone are discussed in more detail for the long-term effectiveness criterion. Hydraulic control, while reducing contaminant mass discharge, would likely not result in the long term reduction of COC concentrations in source area groundwater and, therefore, would not significantly reduce the timeframes required to meet ARARs in the source area. Likewise, hydraulic control in the source area will not reduce time-frames to achieve ARARs at the downgradient portion of the plume because the chlorinated ethene mass entrained in the rock matrix throughout the plume extent will continue to back-diffuse over long periods of time, serving as a continuing source of contaminant mass to the down-gradient portion of the plume.

6.2.3.3. Long-Term Effectiveness and Permanence

As discussed above, hydraulic control would likely not result in the long term reduction of COC concentrations in source area groundwater. While some minor improvements in groundwater quality would be achieved, the FRACTRAN modeling has demonstrated that the time to achieve these benefits is very long and concentrations still remain elevated for very long time periods (i.e., on the order of several hundred years).

This alternative provides a robust monitoring system to document groundwater quality and natural attenuation of contaminants through rock matrix diffusion processes, degradation, retardation, dispersion, adsorption, and mineral precipitation. Groundwater use would be controlled using well restrictions in a groundwater CEA. The long-term effectiveness of natural attenuation processes was evaluated using the FRACTRAN model. The model results indicate that chlorinated ethenes will persist at concentrations exceeding ARARs for very long time periods. However, the expectation is that the rate of plume front migration is very slow due to the effects of matrix diffusion.

6.2.3.4. Reduction of Toxicity, Mobility, and Volume

Alternative 3 would partially meet the preference in CERCLA for on-site treatment and would result in a reduction of mobility in COCs as long as the system is in operation. Hydraulic control would not result in a significant reduction of COC volume in the source area since most of the COC mass is present in the rock matrix and removal would be limited by the rate at which COCs would back-diffuse from the matrix to the groundwater. While hydraulic control would result in the reduction of COC mass discharge from the source, source “cut-off” at plumes in fractured sedimentary rock often does not improve conditions downgradient in the plume (Parker et al, 2010). This was verified by the results of the CDE OU3 FRACTRAN model future projection scenario, in which the complete removal of the source term was simulated, and only minor improvements in downgradient water quality were obtained after extended periods of time.

6.2.3.5. Short-Term Effectiveness

Construction activities for this alternative include drilling extraction wells, construction of a groundwater treatment building (including power supply), installation of underground piping from the extraction wells to the treatment building, and the establishment of a discharge point to either Bound Brook or the MCUA sewer. These activities could result in a low to moderate risk to workers through potential exposure to electrical hazards, mechanical hazards, and noise hazards. The majority of these hazards can be controlled using engineering controls such as lockout/tagout procedures, safe work practices, and personal protective equipment.

Implementation of the MNA portion of this remedy would involve the drilling and installation of four additional deep monitoring wells (average depth of 500 feet), so there would be risks to workers commensurate with drilling activities. There would be a low risk to workers during groundwater sampling activities. There would be low risk to the community during the MNA period, since the monitoring wells would be capped and locked, all sampling and purge water would be contained and properly disposed, and traffic controls would be maintained during sampling for any wells installed in or near roadways.

6.2.3.6. Implementability

Groundwater extraction is a commonly used technology and would be implementable using readily available technologies. Additional evaluation and possible pilot testing may be required to refine the groundwater treatment train. The components of the proposed treatment trains for Alternatives 3a and 3b are commonly used and readily available. Alternative 3b would require a slightly more rigorous treatment train than that required for Alternative 3a to remove elevated metals (e.g., arsenic) prior to water discharge to Bound Brook. In addition, a NJPDES permit would be required to implement Alternative 3b. The MNA portion of this alternative would be straightforward to implement. Monitoring well installation and maintenance, multi-level sampling system installation, and groundwater sampling are well-known technologies and procedures. Services and materials would be readily available to install the monitoring wells and multi-level monitoring systems.

6.2.3.7. Cost

Detailed costs are shown in Tables 6-3a and 6-3b. Capital costs for Alternative 3a are estimated to be \$3,779,000, and for Alternative 3b are estimated to be \$2,721,000. Annual O&M costs, including operation of the groundwater treatment plant and discharge of treated groundwater, are estimated to be \$1,210,000 for Alternative 3a and \$809,000 for Alternative 3b. The total present worth for Alternative 3a is \$38,964,000 and for Alternative 3b is \$29,285,000; these costs include 30 years of groundwater extraction and treatment and 30 years of MNA (\$9,170,000).

6.2.4. Alternative 4: Source Area Thermal Treatment with MNA and ICs

Alternative 4 involves thermal treatment using TCH and SEE. The goal is to remove contaminant mass from the source area located at the former CDE facility in the vicinity of MW-14. Alternative 4 includes implementation of institutional controls as well as detailed monitoring for natural attenuation, as discussed for Alternative 2.

6.2.4.1. Overall Protection of Human Health and the Environment

Under this alternative, potential human exposure to groundwater would be controlled by the establishment of a groundwater CEA. The use of thermal treatment in the treatment area around MW-14 would remove primarily chlorinated ethene contaminant mass. Monitoring of groundwater near the treatment area would document the performance of the thermal treatment. Monitoring of groundwater would also be performed to document the extent and levels of groundwater contamination within the CEA and within the TI zone, and to verify that contaminants do not migrate beyond these areas. Natural attenuation parameters would be analyzed to document the conditions for natural degradation.

6.2.4.2. Compliance with ARARs

Groundwater numerical concentration ARARs have been waived for the TI zone. Concentrations of COCs would decrease through time within the TI zone. Estimated time frames to achieve ARARs in the TI zone are discussed in more detail for the long-

term effectiveness criterion. The removal and treatment of chlorinated ethenes (and, potentially, a portion of the PCB, pesticide, and PAHs mass) would decrease the time-frames required to meet ARARs in the area surrounding MW-14. However, thermal treatment in this area may not reduce time-frames to achieve ARARs at the downgradient portion of the plume because the chlorinated ethene mass entrained in the rock matrix throughout the plume extent will continue to back-diffuse over long periods of time, serving as a continuing source of contaminant mass to the down-gradient portion of the plume.

6.2.4.3. Long-Term Effectiveness and Permanence

The removal of chlorinated ethene mass (and potentially a portion of heavier organic COC mass) would be permanent and would accelerate the time needed to achieve ARARs in this portion of the plume. The impact of source removal (in this case, via thermal treatment) on groundwater concentrations throughout the plume was evaluated using the FRACTRAN model. The model results indicate that source area treatment have little impact on the persistence of the downgradient plume. While some minor improvements in groundwater quality within the plume are achieved from source area treatment, the time to achieve these benefits is very long and concentrations still remain elevated for very long time periods (i.e., on the order of several hundred years).

This alternative provides a robust monitoring system to document groundwater quality and natural attenuation of contaminants through rock matrix diffusion processes, degradation, retardation, dispersion, adsorption, and mineral precipitation. Groundwater use would be controlled using well restrictions in a groundwater CEA. The long-term effectiveness of natural attenuation processes was evaluated using the FRACTRAN model. The model results indicate that chlorinated ethenes will persist at concentrations exceeding ARARs for very long time periods. However, the expectation is that the rate of plume front migration is very slow due to the effects of matrix diffusion.

6.2.4.4. Reduction of Toxicity, Mobility, and Volume

The thermal treatment would partially meet the preference in CERCLA for treatment on site, because this remedy would result in reduction of COC volume in the groundwater fractures in the vicinity of MW-14. The fate of dissolved and adsorbed contaminant mass within the rock matrix is uncertain. However, it may be assumed that at least a portion of the contaminant mass in the rock matrix in the area of influence of the thermal treatment would be volatilized and would back diffuse and be captured by the extraction system. The thermal treatment would also result in at least a temporary reduction in mobility of COCs from the MW-14 area to downgradient portions of the plume. However, as discussed by Parker et al (2010), source removal at plumes in fractured sedimentary rock often does not improve conditions downgradient in the plume. This was verified by the results of the CDE OU3 FRACTRAN model future projection scenario in which the complete removal of the source term was simulated and only minor improvements in downgradient water quality were obtained after extended periods of time.

6.2.4.5. Short-Term Effectiveness

Construction activities for the thermal treatment portion of this alternative include drilling of heater and steam wells, MPE and SVE wells, and temperature and pressure monitoring points. Activities also include installation of well-field piping, construction of a vapor cover, setup of TCH power equipment and a steam generation system, and electrical wiring installation. These activities could result in a moderate risk to workers. An above-ground treatment system for vapor and water would also be constructed. Construction of this treatment system could result in low risk to workers. Thermal treatment operations would be performed over a span of approximately five months. During this time, workers might be exposed to hazards related to thermal burns (e.g., from contact with steam), electrical hazards, mechanical hazards, noise hazards, and other potential hazards. The majority of these hazards can be controlled using engineering controls such as lockout/tagout procedures, safe work practices (e.g., labeling hot surfaces and waiting until equipment cools before using it), and/or personal protective equipment (e.g., heat resistant clothing, face shields, gloves, ear protection, boots, and hard hat). The thermal treatment will be performed over an approximately 1-acre area. An appropriate exclusion zone would be established around the area and it is expected that risks to workers or others outside the exclusion zone would be minimal during thermal treatment operations. Although the SVE and MPE wells should capture nearly all of the vapor generated in the treatment area, complete capture will be difficult to verify in the fractured rock setting at OU3. There is a potential that steam or warm water not captured by the extraction systems could discharge to Bound Brook.

Implementation of the MNA portion of this remedy would involve the drilling and installation of four additional deep monitoring wells (average depth of 500 feet), so there would be risks to workers commensurate with drilling activities. There would be a low risk to workers during groundwater sampling activities. There would be low risk to the community during the MNA period, since the monitoring wells would be capped and locked, all sampling and purge water would be contained and properly disposed, and traffic controls would be maintained during sampling for any wells installed in or near roadways.

6.2.4.6. Implementability

There are several technical difficulties involved with implementing thermal treatment in fractured bedrock. One of the most significant is the ability to hydraulically control the steam injections in a fractured rock setting. Also, since it is not feasible to dewater the treatment area due to the productive zone at approximately 65 feet bgs, target temperatures are limited to 100°C, limiting treatment of PCBs, pesticides, and PAHs, which typically require temperatures in excess of 325°C for vaporization. Because the energy usage is significant during thermal treatment operations, coordination may be required with the local energy utility to boost electrical service to the Site. A temporary discharge authorization would be required from MCUA to discharge treated condensate (the vapor treatment system would need to meet MCUA's effluent criteria, provided in Appendix D). TCH and SEE are currently widely applied at a variety of sites at both

pilot and full-scale. Several vendors offer TCH and SEE services, and have the personnel and equipment to address multiple sites concurrently.

The MNA portion of this alternative would be straightforward to implement. Monitoring well installation and maintenance, multi-level sampling system installation, and groundwater sampling are well-known technologies and procedures. Services and materials would be readily available to install the monitoring wells and multi-level monitoring systems.

6.2.4.7. Cost

Detailed costs are shown in **Table 6-4**. Capital costs for this alternative are estimated to be \$14,069,000. There are no O&M costs associated with thermal treatment since the entire thermal treatment operation will be completed within one year (it is assumed that costs for five-year CERCLA reviews are included in the MNA costs). The present worth cost for 30 years of MNA is estimated at \$9,170,000. The total present worth of this alternative is \$23,239,000.

6.2.5. Alternative 5: Source Area In Situ Chemical Oxidation with MNA and ICs

Alternative 5 involves ISCO treatment using activated persulfate to remove contaminant mass from the source area located at the former CDE facility in the vicinity of MW-14. Alternative 5 includes implementation of institutional controls as well as detailed monitoring for natural attenuation, as discussed for Alternative 2.

6.2.5.1. Overall Protection of Human Health and the Environment

Under this alternative, potential human exposure to groundwater would be controlled by the establishment of a groundwater CEA. The CEA provides an institutional control through a notice that there is groundwater contamination in the area. It also gives the State the authority to restrict the installation of wells and the use of groundwater in the CEA. The use of ISCO treatment in the treatment area around MW-14 would remove organic COCs including chlorinated ethenes, PCBs, pesticides, and PAHs. Monitoring of groundwater near the treatment area would document the performance of the ISCO treatment. Monitoring of groundwater would also be performed to document the extent and levels of groundwater contamination within the CEA and within the TI zone, and to verify that contaminants do not migrate beyond these areas. Natural attenuation parameters would be analyzed to document the conditions for natural degradation.

6.2.5.2. Compliance with ARARs

Groundwater numerical concentration ARARs have been waived for the TI zone. Concentrations of COCs would decrease through time within the TI zone. Estimated time frames to achieve ARARs in the TI zone are discussed in more detail for the long-term effectiveness criterion. The removal and treatment of organic COCs would decrease the time-frames required to meet ARARs in the area surrounding MW-14. However, ISCO treatment in this area may not reduce time-frames to achieve ARARs at the

downgradient portion of the plume because the chlorinated ethene mass entrained in the rock matrix throughout the plume extent will continue to back-diffuse over long periods of time, serving as a continuing source of contaminant mass to the down-gradient portion of the plume.

6.2.5.3. Long-Term Effectiveness and Permanence

The oxidation of organic COCs would be permanent and would reduce the time needed to achieve ARARs in this portion of the plume (i.e., in the vicinity of MW-14). The impact of source removal (in this case, via ISCO) on groundwater concentrations throughout the plume was evaluated using the FRACTRAN model. The model results indicate that source area treatment will have little impact on the persistence of the downgradient plume. While some minor improvements in groundwater quality within the plume are achieved from source area treatment, the time to achieve these benefits is very long and concentrations still remain elevated for very long time periods (i.e., on the order of several hundred years).

This alternative provides a robust monitoring system to document groundwater quality and natural attenuation of contaminants through rock matrix diffusion processes, degradation, retardation, dispersion, adsorption, and mineral precipitation. Groundwater use would be controlled using well restrictions in a groundwater CEA. The long-term effectiveness of natural attenuation processes was evaluated using the FRACTRAN model. The model results indicate that chlorinated ethenes will persist at concentrations exceeding ARARs for very long time periods. However, the expectation is that the rate of plume front migration is very slow due to the effects of matrix diffusion.

6.2.5.4. Reduction of Toxicity, Mobility, and Volume

The ISCO treatment would partially meet the preference in CERCLA for treatment on-Site, because this remedy would result in reduction of COC volume in the groundwater fractures in the vicinity of MW-14. The fate of dissolved and adsorbed contaminant mass within the rock matrix is uncertain. However, it is assumed that at least a portion of the contaminant mass within the rock matrix would be treated via chemical oxidation. The ISCO treatment would also result in at least a temporary reduction in mobility of COCs from the MW-14 area to downgradient portions of the plume. However, as discussed by Parker et al (2010), source removal at plumes in fractured sedimentary rock often does not improve conditions downgradient in the plume. This was verified by the results of the CDE OU3 FRACTRAN model future projection scenario in which the complete removal of the source term was simulated and only minor improvements in downgradient water quality were obtained after extended periods of time.

6.2.5.5. Short-Term Effectiveness

Construction activities for the ISCO treatment portion of this alternative include drilling of injection wells, which may pose moderate risks to site workers. ISCO treatment operations involve storage and handling of sodium persulfate and sodium hydroxide. ISCO operations pose moderate to high risks to site workers. During ISCO operations,

workers are exposed to hazards related to chemical exposure (e.g., skin burns, irritation to eyes, nose, lungs, and throat). They are also exposed to hazards related to combustion, since sodium persulfate decomposes during storage and can cause release of oxides that support combustion. These hazards can be controlled using appropriate chemical storage procedures and appropriate personal protection equipment. The work site should be set up so the oxidant will be properly contained in the event of a leak from the storage container. Protective safety equipment should include a portable eyewash and shower in the event of an accidental exposure to the chemicals. The ISCO treatment will be performed over an approximately 1-acre area. An appropriate exclusion zone would be established around the area and it is expected that risks to workers or others outside the exclusion zone would be minimal during ISCO operations. Since shallow groundwater from the former CDE facility potentially discharges to Bound Brook, there is a potential that sodium persulfate and /or sodium hydroxide could enter the stream. These chemicals, in sufficient quantities, could negatively impact water quality in the stream and pose unacceptable risks to ecological receptors. However, given the fairly small quantities of persulfate to be applied during each injection event (i.e., half of a pore volume within the treatment area) it is not likely that any chemical discharges to Bound Brook related to ISCO operations would impact water quality.

Implementation of the MNA portion of this remedy would involve the drilling and installation of two additional deep monitoring wells (depth of 500 feet), so there would be risks to workers commensurate with drilling activities. There would be a low risk to workers during groundwater sampling activities. There would be low risk to the community during the MNA period, since the monitoring wells would be capped and locked, all sampling and purge water would be contained and properly disposed, and traffic controls would be maintained during sampling for any wells installed in or near roadways.

6.2.5.6. Implementability

There are several technical difficulties involved with implementing ISCO treatment in fractured bedrock. The most significant difficulty pertains to achieving oxidant distribution throughout the fracture network. ISCO is effective only if the oxidant directly contacts the contaminants to be treated. It is assumed that an ISCO pilot study will need to be performed prior to full-scale design and implementation to refine the achievable injection radius of influence. The rock oxidant demand for the rock at OU3 will need to be determined in a treatability study to determine how much of the persulfate oxidant will be consumed by minerals present in the rock matrix. ISCO effectiveness at OU3 will also be limited by mass transfer limitation (i.e., matrix diffusion of contaminants in the bedrock). ISCO will generally only be effective for contaminants that are contained in the rock fractures. ISCO with persulfate is currently widely applied at a variety of sites at both pilot and full-scale. Several vendors offer ISCO application services and have the personnel and equipment to address multiple sites concurrently. To implement ISCO in New Jersey, a NJPDES permit equivalency is required in accordance

with the Technical Requirements for Site Remediation pursuant to the NJAC Section 7:26E and the NJPDES rules in NJAC 7:14A.

The MNA portion of this alternative would be straightforward to implement. Monitoring well installation and maintenance, multi-level sampling system installation, and groundwater sampling are well-known technologies and procedures. Services and materials would be readily available to install the monitoring wells and multi-level monitoring systems.

6.2.5.7. Cost

Detailed costs are shown in **Table 6-5**. Capital costs for this alternative are estimated to be \$1,872,000. Annual O&M costs (to be incurred in Years 2 to 6), including quarterly ISCO injections, are \$754,000. The total present worth of this alternative is \$14,307,000; this includes five years of ISCO injections, as well as 30 years of MNA, which is estimated at \$9,170,000.

6.2.6. Alternative 6: Source Area In Situ Bioremediation with MNA and ICs

Alternative 6 involves the use of *in situ* biological treatment using an EVO as a carbon substrate, as well as bioaugmentation with microbial cultures, to remove contaminant mass from the source area located at the former CDE facility in the vicinity of MW-14. Alternative 6 includes implementation of institutional controls as well as detailed monitoring for natural attenuation, as discussed for Alternative 2.

6.2.6.1. Overall Protection of Human Health and the Environment

Under this alternative, potential human exposure to groundwater would be controlled by the establishment of a groundwater CEA. The CEA provides an institutional control through a notice that there is groundwater contamination in the area. It also gives the State the authority to restrict the installation of wells and the use of groundwater in the CEA. The use of *in situ* biological treatment in the treatment area around MW-14 would remove organic COCs, primarily chlorinated ethenes. The other classes of organic compounds present at the source area (i.e., PCBs, pesticides, and PAHs) are not as likely to biodegrade. Monitoring of groundwater near the treatment area would document the performance of the *in situ* biological treatment. Monitoring of groundwater would also be performed to document the extent and levels of groundwater contamination within the CEA and within the TI zone, and to verify that contaminants do not migrate beyond these areas. Natural attenuation parameters would be analyzed to document the conditions for natural degradation.

6.2.6.2. Compliance with ARARs

Groundwater numerical concentration ARARs have been waived for the TI zone. Concentrations of COCs would decrease through time within the TI zone. Estimated time frames to achieve ARARs in the TI zone are discussed in more detail for the long-term effectiveness criterion. The removal and treatment of chlorinated ethene COCs would decrease the time-frames required to meet ARARs in the area surrounding MW-

14. However, *in situ* biological treatment in this area may not reduce time-frames to achieve ARARs at the downgradient portion of the plume because the chlorinated ethene mass entrained in the rock matrix throughout the plume extent will continue to back-diffuse over long periods of time, serving as a continuing source of contaminant mass to the down-gradient portion of the plume.

6.2.6.3. Long-Term Effectiveness and Permanence

The removal of chlorinated ethene mass would be permanent and would accelerate the time needed to achieve ARARs in this portion of the plume. The impact of source removal (in this case, via *in situ* biological treatment) on groundwater concentrations throughout the plume was evaluated using the FRACTRAN model. The model results indicate that source area treatment have little impact on the persistence of the downgradient plume. While some minor improvements in groundwater quality within the plume are achieved from source area treatment, the time to achieve these benefits is very long and concentrations still remain elevated for very long time periods (i.e., on the order of several hundred years).

This alternative provides a robust monitoring system to document groundwater quality and natural attenuation of contaminants through rock matrix diffusion processes, degradation, retardation, dispersion, adsorption, and mineral precipitation. Groundwater use would be controlled using well restrictions in a groundwater CEA. The long-term effectiveness of natural attenuation processes was evaluated using the FRACTRAN model. The model results indicate that chlorinated ethenes will persist at concentrations exceeding ARARs for very long time periods. However, the expectation is that the rate of plume front migration is very slow due to the effects of matrix diffusion.

6.2.6.4. Reduction of Toxicity, Mobility, and Volume

The *in situ* biological treatment would partially meet the preference in CERCLA for treatment on site, because this remedy would result in reduction of COC volume in the groundwater fractures in the vicinity of MW-14. The fate of dissolved and adsorbed contaminant mass within the rock matrix is uncertain. However, it is assumed that at least a portion of the contaminant mass within the rock matrix would be treated via *in situ* biological treatment. Bioremediation treatment would also result in at least a temporary reduction in mobility of COCs from the MW-14 area to downgradient portions of the plume. However, as discussed by Parker et al (2010), source removal at plumes in fractured sedimentary rock often does not improve conditions downgradient in the plume. This was verified by the results of the CDE OU3 FRACTRAN model future projection scenario in which the complete removal of the source term was simulated and only minor improvements in downgradient water quality were obtained after extended periods of time.

6.2.6.5. Short-Term Effectiveness

Construction activities for the *in situ* biological treatment portion of this alternative include drilling of injection wells, which may pose moderate risks to site workers. The

proposed bioremediation treatment operations involve storage and handling of EVO and microbial cultures. EVO is a food-grade product that poses minimal health risks to workers. Although the dechlorinating bacteria cultures do not contain virulent pathogens, standard hygienic procedures should be observed by site workers to avoid contact with the bacterial culture solutions. The work site should be set up so that remediation amendments will be properly contained in the event of a leak from the storage container. Protective safety equipment should include a portable eyewash and shower in the event of an accidental exposure to the chemicals. The biological treatment will be performed over an approximately 1-acre area. An appropriate exclusion zone would be established around the area and it is expected that risks to workers or others outside the exclusion zone would be minimal during *in situ* biological treatment operations. Since shallow groundwater from the former CDE facility potentially discharges to Bound Brook, there is a potential that biological treatment amendments could enter the stream. These chemicals could negatively impact water quality in the stream and pose unacceptable risks to ecological receptors.

Implementation of the MNA portion of this remedy would involve the drilling and installation of two additional deep monitoring wells (depth of 500 feet), so there would be risks to workers commensurate with drilling activities. There would be a low risk to workers during groundwater sampling activities. There would be low risk to the community during the MNA period, since the monitoring wells would be capped and locked, all sampling and purge water would be contained and properly disposed, and traffic controls would be maintained during sampling for any wells installed in or near roadways.

6.2.6.6. Implementability

There are several technical difficulties involved with implementing *in situ* biological treatment in fractured bedrock. The most significant difficulty pertains to achieving adequate distribution of the amendments throughout the fracture network to establish conditions conducive to the growth of dechlorinating bacteria. It is assumed that an *in situ* bioremediation pilot study will need to be performed prior to full-scale design. The purpose of the pilot study would be to evaluate the efficacy of the technology and to establish design parameters for spacing of injection wells and for establishing required frequency of substrate application. The effectiveness of *in situ* biological treatment at OU3 will be limited by mass transfer limitation (i.e., matrix diffusion of contaminants in the bedrock). *In situ* bioremediation will generally only be effective for contaminants that are contained in the rock fractures (i.e., in the aqueous phase). *In situ* biological treatment using EVO is currently widely applied at a variety of sites at both pilot and full-scale. Several vendors offer various formulations of EVOs, and there are several suppliers of specialized dechlorinating bacterial microbial cultures; therefore, both these types of amendments are readily available. Also, there are several firms that specialize in the injection of remediation amendments, and several have offices / equipment in New Jersey. To inject the proposed amendments into the subsurface in New Jersey, a NJPDES

permit equivalency is required in accordance with the Technical Requirements for Site Remediation pursuant to the NJAC Section 7:26E and the NJPDES rules in NJAC 7:14A.

The MNA portion of this alternative would be straightforward to implement. Monitoring well installation and maintenance, multi-level sampling system installation, and groundwater sampling are well-known technologies and procedures. Services and materials would be readily available to install the monitoring wells and multi-level monitoring systems.

6.2.6.7. Cost

Detailed costs are shown in Table 6-6. Capital costs for this alternative are estimated to be \$1,983,000. Annual O&M costs (to be incurred in Years 2 to 11), including annual applications of bioremediation amendments, are \$134,000. The total present worth of this alternative is \$12,311,000; this includes ten years of bioremediation amendment injections, as well as 30 years of MNA, which is estimated at \$9,170,000.

6.3. Comparative Analysis of Alternatives

The purpose of the comparative analysis of alternatives is to evaluate the relative performance of each alternative for each of the seven evaluation criteria. A summary of the six alternatives relative to the evaluation criteria (with the exception of costs, which are shown on Table 6-7) is presented in Table 6-8. A comparison of the alternatives for each of the evaluation criteria is provided below.

6.3.1. Overall Protection of Human Health and the Environment

With the exception of Alternative 1 (No Action), all of the alternatives include institutional controls to mitigate identified potential risks resulting from exposure to groundwater through pathway elimination. Therefore, Alternatives 2 through 6 would be protective of human health and the environment. Alternative 1 would not be protective of human health and the environment since it does not include measures to prevent exposure to groundwater.

6.3.2. Compliance with ARARs

A TI Zone has been established to capture OU3 and ARARs have been waived within the TI Zone.

6.3.3. Long-Term Effectiveness and Permanence

As discussed previously, the FRACTRAN model results indicate that source area treatment will have little impact on the persistence of the downgradient plume. While some minor improvements in groundwater quality within the plume are achieved from source area treatment, the time to achieve these benefits is very long and concentrations still remain elevated for very long time periods (i.e., on the order of several hundred years).

The long-term effectiveness of natural attenuation processes was evaluated using the FRACTRAN model. The model results indicate that chlorinated ethenes will persist at concentrations exceeding ARARs for very long time periods. However, the expectation is that the rate of plume front migration is very slow due to the effects of matrix diffusion. Therefore, although Alternatives 3, 4, 5, and 6 may locally improve groundwater quality, the long-term effectiveness of all the alternatives, including Alternative 2 (MNA with ICs), would be equal.

6.3.4. Reduction of Toxicity, Mobility, and Volume

Alternatives 4 (Thermal Treatment), 5 (ISCO), and 6 (Bioremediation) would all partially meet the preference in CERCLA for treatment on site and would result in a reduction in the volume of COCs in the MW-14 area, and at least a temporary reduction in mobility of COCs to downgradient portions of the plume. Alternative 3 (Hydraulic Control), would result in a reduction of mobility to downgradient portions of the plume as long as the system is in operation. Of these alternatives, Alternative 4 would likely be the most effective overall. However, as it has been demonstrated that source removal at plumes in fractured sedimentary rock will not likely improve conditions downgradient in the plume, all of the alternatives, including Alternative 2 (MNA with ICs), would be equal equally effective at reducing toxicity, mobility, and volume of the entire OU3 area.

6.3.5. Short-Term Effectiveness

Alternatives 3 (Hydraulic Control), 4 (Thermal Treatment), and 5 (ISCO) would involve construction and/or in-situ treatment hazards that could pose a risk to site workers or the surrounding environment. However, it is anticipated that these risks could be mitigated through the use of engineering controls, safe work practices, and personal protective equipment. All of the alternatives except Alternative 1 (No Action) involve the drilling and sampling of monitoring wells, which is expected to pose minimal risks to site workers and the surrounding environment.

6.3.6. Implementability

Alternative 2 (MNA with ICs) could be readily implemented using commonly available technologies and with minimal design or permitting. Alternatives 3 (Hydraulic Control), 5 (ISCO), and 6 (Bioremediation) could also be readily implemented; however, all three would require permitting (underground injection or surface water/sewer discharge). Alternatives 5 and 6 would require some design as well as bench and/or field-scale pilot testing, while Alternative 3 would require full-scale plans and specifications for construction of the groundwater extraction and treatment infrastructure. Alternative 4 would likely be the most difficult to implement due to the energy, permitting, and heating controls/infrastructure required.

6.3.7. Cost

The costs for Alternatives 1 through 6 are summarized on Table 6-7. Capital costs, operations and maintenance costs, and monitoring costs were developed for each alternative. Scope and bid contingencies, as well as design and project management

costs, were added in accordance with USEPA's Guide to Developing and Documenting Cost Estimates During the Feasibility Study (USEPA, 2000). The estimate accuracy of the costs is -30% to +50%. As discussed in Section 6.1.2, a discount rate of 2.3% was applied to calculate present value costs. Each alternative has an estimated duration of 30 years; although, as discussed above, it is anticipated that contaminant concentrations will exceed ARARs for much longer time periods. Tables 6-1 to 6-6 also present the non-discounted values of each alternative.

The costs for each alternative (except for Alternative 1) were developed on the basis of preliminary engineering designs to meet the RAOs. The estimated present value costs range from \$2.1 million to \$39 million. This wide range in costs for the alternatives results from the following factors:

- Alternative 1 has the lowest present value cost because it includes only cursory monitoring to support preparation of CERCLA five-year reviews. Costs are still significant, however, because each of the five assumed monitoring locations contains multi-level ports, and because monitoring would be required for a minimum of 30 years.
- Although Alternative 2 involves only installation of four wells followed by regular monitoring of the new wells and existing wells, the monitoring program to support the TI waiver is extensive. The program includes collection of samples from twelve existing shallow bedrock wells, as well as 22 existing deep bedrock wells (each with multiple sample ports, for a total of 126 ports) and four new deep bedrock wells that are assumed to each contain nine sample ports. The list of analytes for wells located on the former CDE facility is extensive, including VOCs, PCBs, pesticides, SVOCs, as well as MNA parameters (the analyte list for wells not located on the facility includes primarily VOCs and MNA parameters).
- The present value estimate for Alternative 3a (\$39 million) is significantly higher than that for Alternative 3b (\$29 million). This is largely because of the large capital cost required to connect to the Borough of South Plainfield's sewer system, and also because of the POTW treatment costs imposed by MCUA and the sewer usage fees imposed by the Borough of South Plainfield. The additional water treatment required to meet NJDEP effluent criteria for FW-2 streams is significantly lower than the fees required to discharge treated water to MCUA.
- Of the three *in situ* source area treatment alternatives (i.e., Alternatives 4, 5, and 6), thermal treatment (Alternative 4) is the most expensive. Drilling and well installation of closely spaced heating points accounts for approximately \$3 million, and electricity usage accounts for approximately \$1.7 million of the total capital cost of approximately \$14 million for thermal treatment.
- The present value of ISCO is estimated to be approximately \$2 million greater than the present value of *in situ* biological treatment. This is because the O&M costs are greater for ISCO than for *in situ* biological treatment because: (1) the cost of the ISCO reagents is greater than that of the biological reagents and (2) greater frequency

of ISCO injections (quarterly for five years) as opposed to biological amendment applications (annually for 10 years) because the oxidants have a much shorter active life than the biological amendments.

7. References

- Air Force Center for Environmental Excellence (AFCEE), Naval Facilities Engineering Service Center, and Environmental Security Technology Certification Program (ESTCP). 2004. Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents. August 2004.
- Bioremediation Consulting, Inc. (BCI). 2010. Final Report. Microcosm Presence/Absence Tests on Groundwater from the Cornell-Dubilier OU-3 Superfund Site. Revised October 7, 2010.
- Borough of South Plainfield. 2011. Borough of South Plainfield, New Jersey. Code of the Borough of South Plainfield, New Jersey. Chapter 352 – Sewers.
- City-Data.com. <http://www.city-data.com>
- Environmental Security Technology Certification program (ESTCP). 2010. Final Report. Critical Evaluation of State-of-the-Art In Situ Thermal Treatment Technologies for DNAPL Source Zone Treatment. ESTCP Project ER-0314. January 2010.
- Feenstra, S. and J.A. Cherry. 1988. Subsurface contamination by dense non-aqueous phase liquid (DNAPL) chemicals. Proceedings of International Groundwater Symposium, International Association of Hydrogeologists, May 1-4, 1988, Halifax, Nova Scotia.
- Fenneman, N.M. 1938. Physiography of Eastern United States. New York: McGraw-Hill.
- FWENC. 2001. Data Evaluation Report for Cornell-Dubilier Electronics Superfund Site. South Plainfield, Middlesex County, New Jersey.
- FWENC. 2002. Final Remedial Investigation Report for Operable Unit 2 (OU2) On-Site Soils and Buildings for Cornell-Dubilier Electronics Superfund Site - South Plainfield, Middlesex County, New Jersey.
- Herman, G.C. 2001. Hydrogeologic Framework of Bedrock Aquifers in the Newark Basin, New Jersey: Field Guide and Proceedings. Geology in Service to Public Health, 18th Annual Meeting, Geologic Association of New Jersey, p. 6-45.
- Heron, Gorm, Ralph S. Baker, John M. Bierschenk, and John C. LaChance. Use of Thermal Conduction Heating for the Remediation of DNAPL in Fractured Bedrock. Remediation of Chlorinated and Recalcitrant Compounds: Proceedings of the Sixth International Conference (May 19-22, 2008). Battelle Press, Columbus, OH.
- Interstate Technology Regulatory Council (ITRC). 2002. DNAPL Source Reduction: Facing the Challenge. April 2002.

- ITRC. 2005. Technical and Regulatory Guidance for In Situ Chemical Oxidation of Contaminated Soil and Groundwater. Second Edition. January 2005.
- ITRC. 2008. In Situ Bioremediation of Chlorinated Ethene: DNAPL Source Zones. June 2008.
- Louis Berger Group, Inc. and Malcolm Pirnie, Inc. 2011a. Draft Baseline Human Health Risk Assessment, Operable Unit 3: Groundwater. Cornell-Dubilier Electronics Superfund Site, South Plainfield, New Jersey. (June 2011)
- Louis Berger Group, Inc. and Malcolm Pirnie, Inc. 2011b. Draft Remedial Investigation Report, Operable Unit 3: Groundwater. Cornell-Dubilier Electronics Superfund Site, South Plainfield, New Jersey. (June 2011)
- Malcolm Pirnie, Inc. 2008a. Final Remedial Investigation/Feasibility Study Work Plan. Cornell-Dubilier Electronics Superfund Site, South Plainfield, New Jersey. Operable Unit 3: Groundwater. (December 2008)
- Malcolm Pirnie, Inc. 2008b. Revised Final Habitat Assessment Report for Operable Unit 2 Soils.
- Michalski, A. 1990. Hydrogeology of Brunswick (Passaic) Formation and implications for Groundwater Monitoring Practices. Groundwater Monitoring Review. Vol. 1 (4): 134-43.
- Michalski, A. and R. Britton. 1997. The Role of Bedding Fractures in the Hydrogeology of Sedimentary Bedrock - Evidence from the Newark Basin, New Jersey. Ground Water. Vol. 35 (2): 318-327.
- Michalski, A. and G.M. Klepp. 1990. Characterization of Transmissive Fractures by Simple Tracing of In-Well Flow. Ground Water. Vol. 28 (2): 191-198.
- Middlesex County Utilities Authority (MCUA). 2010. Rules and Regulations of the Middlesex County Utilities Authority, Sayreville, New Jersey.
- National Oceanic and Atmospheric Administration (NOAA). 1999. Coastal Hazardous Waste Site Review, Cornell Dubilier Electronics, Inc.
http://response.restoration.noaa.gov/book_shelf/339_Cornell.pdf
- New Jersey Geological Survey. 2004. Arsenic in New Jersey Ground Water.
<http://www.state.nj.us/dep/njgs/enviroed/infocirc/arsenic.pdf>
- Parker, B.L., R.W. Gilham and J.A. Cherry. 1994. Diffusive disappearance of immiscible-phase organic liquids in fractured geologic media. Ground Water, 32(5): 805-820.
- Parker, B. L. 2007. Investigating Contaminated Sites in Fracture Rock Using the DFN Approach. Proceedings of 2007 USEPA/NGWA Fractured Rock Conference: State of the Science and Measuring Success in Remediation, September 24-26, 2007, Portland, Maine.

- Parker, Beth, S.W. Chapman and J.A. Cherry, 2010. Plume Persistence in Fractured Sedimentary Rock After Source Zone Removal. Ground Water. Vol. 48, No. 6, pp. 799-803.
- TerraTherm. 2010. ESTCP-Sponsored TCH Demonstration: Former Naval Air Warfare Center, West Trenton, New Jersey.
<http://www.terraetherm.com/pdf/revisedESTCPCinfosheet.pdf>
- United States Department of Energy (USDOE). 2000. Hydrous Pyrolysis Oxidation / Dynamic Underground Stripping Demonstrated at Visalia Superfund Site, Visalia, California. DOE/EM-0504. February 2000.
- U.S. Environmental Protection Agency (USEPA).1986. Guidelines for Carcinogen Risk Assessment. EPA/630/R-00/004. Risk Assessment Forum, Washington, DC. September 1986
- USEPA. 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. October 1988.
- USEPA. 1989. Risk Assessment Guidance for Superfund. Volume I: Human Health Evaluation Manual (Part A). Interim Final. EPA/540/1-89/002. Office of Emergency and Remedial Response, Washington, DC. December 1989. USEPA, 1991. A Guide to Principal Threat and Low Level Threat Wastes. Office of Solid Waste and Emergency Response. Superfund Publication: 9380.3-06FS. November 1991.
- USEPA. 1996. Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites. Directive 9283.1-12. EPA 540/R-96/023. October 1996.
- USEPA. 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater. Office of Research and Development. EPA/600/R-98/128.
- USEPA. 2000. A Guide to Developing and Documenting Cost Estimates During the Feasibility Study. EPA 54-R-00-002. OSWER 9355.0-75. July 2000.
- USEPA. 2001. Response to Request for Information. Forwarded to Foster Wheeler Environmental Corporation by U.S. Environmental Protection Agency. (9 May 2001)
- USEPA. 2002. Arsenic Treatment Technologies for Soil, Waste, and Water. EPA-542-R-02-004. September 2002.
- USEPA. 2005. Steam-Enhanced Remediation Research for DNAPL in Fractured Rock, Loring Air Force Base, Limestone, Maine. EPA/540/R-05/010. August 2005.
- Van den Berg, M., Birnbaum, L.S., Denison, M., De Vito, M., Farland, W., Feeley, M., Fiedler, H., Hakansson, H., Hanberg, A., Haws, L., Rose, M., Safe, S., Schrenk, D., Tohyama, C., Tritscher, A., Tuomisto, J., Tysklind, M., Walker, N., and Peterson, R.E., 2006. The 2005 World Health Organization Re-evaluation of

Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-like Compounds. Toxicological Sciences, July 2006.

TABLE 1-1
CHRONOLOGY OF EVENTS AND SITE INVESTIGATIONS
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

DATE	EVENT
1912 – mid/late 1920s	Spicer Manufacturing Company operated a manufacturing plant on the Site; most of the major structures were erected by 1918.
1936 – 1962	CDE facility in operation, manufacturing of electronic components including capacitors led to disposal of PCB-contaminated materials and other hazardous substances directly on the facility soils.
1962 – 2007	CDE vacated the facility and since then the facility has operated as a rental property consisting of a variety of commercial and light industrial tenants.
1986	NJDEP began investigation of the environmental conditions at the former CDE facility. Preliminary sampling by the NJDEP and the USEPA showed the presence of elevated concentrations of PCBs, VOCs, and inorganic chemicals in facility soils, sediments, and surface water.
1997	The USEPA conducted a preliminary investigation of Bound Brook and collected surface soil and interior dust samples from nearby residential and commercial properties. These investigations lead to fish consumption advisories for Bound Brook and its tributaries.
March 1997	USEPA ordered the owner of the facility property to perform a removal action associated with contaminated soil and surface water runoff from the facility. The removal action included paving driveways and parking areas in the industrial park, installing a security fence, and implementing drainage controls.
1998	The Site was added to the National Priorities List as a result of the 1997 sampling activities. The USEPA initiated a removal action to address PCBs in interior dust at houses to the west and southwest of the facility.
1998- 2000	The USEPA ordered CDE and Dana Corporation to implement removal actions to address PCBs in soils at six residential properties in 1998 and seven additional properties in 1999 that were located to the west and southwest of the facility. The first removal action was completed in 1999 and the second in 2000.
2000	Foster Wheeler, Inc. conducted an RI that included the collection of soil, sediment, and building surface samples, as well as the installation and sampling of 12 shallow bedrock monitoring wells. The USEPA then divided the Site into four OUs: OU1 addresses residential, commercial, and municipal properties in the vicinity of the former CDE facility, OU2 addresses facility soils and buildings, OU3 addresses groundwater, and OU4 addresses the Bound Brook.
2001	USEPA issued the RI and FS for OU1.
September 30, 2003	USEPA signed a Record of Decision to address OU1 and OU2. The selected remedy included the removal of approximately 2,100

TABLE 1-1
CHRONOLOGY OF EVENTS AND SITE INVESTIGATIONS
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

	cubic yards of contaminated soils from neighboring properties, as well as indoor dust remediation where PCB contaminated dust was identified. Additional sampling was proposed to determine if further remediation was required.
April 2004	The FS for OU2 was issued.
September 2004	The ROD for OU2 was issued. The remedy specified in the ROD included excavation of an estimated 114,500 cubic yards of contaminated soil, on-site treatment of excavated soils, transportation of contaminated soil and debris no suitable for LTDD treatment, installation of a multilayer cap or hardscape, installation of engineering controls, property restoration, and implementation of institutional controls.
November 2006	USEPA began implementing the OU2 ROD with the relocation of facility tenants at the industrial park and began demolition of the 18 buildings.
December 2007	Scope of work was transmitted to Malcolm Pirnie, Inc.
May 2008	Building demolition completed.
January 2008	Eight deep bedrock wells were installed by USEPA to assess the hydraulic properties of the fractured bedrock and water quality of the bedrock groundwater up- and down-gradient of the former CDE facility. Groundwater samples were collected for VOCs from multiple depths and also were taken from 12 existing shallow bedrock monitoring wells located at the former CDE facility. Initial testing indicated the presence of chlorinated VOCs in 11 of the 12 shallow bedrock wells.
October 2008	A Final Remedial Investigation/Feasibility Study Work Plan and Final Site-Wide Site Safety and Health Plan for All Operable Units were submitted to the USEPA.
December 2008	A Final Field Sampling Plan was submitted to the USEPA.
January - June 2009	Malcolm Pirnie performed rock core sampling and analyses to assess the presence of VOCs and PCBs in the rock matrix and completed borehole drilling and installation of temporary FLUTE liners for future monitoring wells.
May - June 2009	Malcolm Pirnie carried out FLUTE liner drop tests to assess hydraulic properties of fractured bedrock zones and completed borehole geophysics.
September - October 2009	Malcolm Pirnie installed FLUTE multi-port monitoring wells to record hydraulic heads and to obtain groundwater samples from fractured bedrock zones.
October 2009	Malcolm Pirnie performed the first sampling event, recording water levels and collected groundwater samples from all monitoring wells.
March 2010	Malcolm Pirnie performed the second sampling event, recording water levels and collected groundwater samples from all

TABLE 1-1
CHRONOLOGY OF EVENTS AND SITE INVESTIGATIONS
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

	monitoring wells, plus select wells for PCB congeners, Dioxins, and Furans..
June 2010	Malcolm Pirnie completed an integral aquifer test to further characterize the source term in bedrock, and to characterize anisotropic groundwater movement in the Passaic Formation at the Site. This included an 8 hour step rate drawdown test, two 48 hour constant rate pumping tests, and the collection of water quality samples of pumping effluent to characterize the mass discharge over time (VOCs, PCBs, physical parameters)
July 2010	Malcolm Pirnie performed the third sampling event, recording water levels from all monitoring wells and collected groundwater samples from select wells for PCB congeners, dioxins, and furans.
September – November 2010	Malcolm Pirnie completed borehole drilling, carried out FLUTE liner drop tests to assess hydraulic properties of fractured bedrock zones and completed borehole geophysics for additional monitoring well MW-23.
December 2010	Malcolm Pirnie completed installation of temporary FLUTE liner in MW-23, conducted first sampling event on MW-23.

TABLE 2-1
OU3 RI MONITORING WELLS
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Well ID	FLUTe™ Well Port #	Sample Interval (ft bgs)		Construction note: Port/depth selection rationale
		Top	Bottom	
Shallow Bedrock Monitoring Wells				
MW-01A	1	24	49	Not Applicable
MW-02A	1	24	49	Not Applicable
MW-03	1	17	32	Not Applicable
MW-04	1	29	49	Not Applicable
MW-05	1	25	45.5	Not Applicable
MW-06	1	29	44	Not Applicable
MW-07	1	43	58	Not Applicable
MW-08	1	42	57.5	Not Applicable
MW-09	1	29	54	Not Applicable
MW-10	1	37	52	Not Applicable
MW-11	1	34	59	Not Applicable
MW-12	1	35	60	Not Applicable
Deep Bedrock Multi-Port Monitoring Wells				
ERT-1	1	24	29	High borehole transmissivity, shallowest interval
	2	33	43	High borehole transmissivity, fracture at 40' bgs
	3	46	56	High borehole transmissivity, fractures at 49' and 51' bgs
	4	59	64	High borehole transmissivity, fracture at 61' bgs
	5	67	77	Fractures at 71' and 75' bgs
	6	100	105	Moderate borehole transmissivity, fracture at 103' bgs
	7	112	117	Moderate borehole transmissivity, fracture at 114' bgs
	8	135	140	Deepest interval, fracture at 137' bgs
ERT-2	1	25	35	Shallowest interval, fracture at 33' bgs
	2	40	50	Moderate borehole transmissivity, fracture at 48' bgs
	3	54	59	Moderate borehole transmissivity
	4	70	75	High borehole transmissivity
	5	97	107	High borehole transmissivity, fracture at 105' bgs
	6	113	123	Moderate borehole transmissivity, fractures at 114' and 119' bgs
	7	127	137	High borehole transmissivity, fracture at 131' bgs
ERT-3	1	27	37	High borehole transmissivity, fracture at 33' bgs
	2	55	65	Fractures at 56' and 65' bgs
	3	90	105	High borehole transmissivity, fractures at 93', 95', 100, and 105' bgs
	4	110	120	Moderate borehole transmissivity
	5	124	134	Moderate borehole transmissivity
	6	138	148	Deepest interval, high resistivity
ERT-4	1	27	37	Shallowest interval, fracture at 35' bgs
	2	46	56	Fractures at 48' and 55' bgs
	3	61	66	Fracture at 65' bgs
	4	83	88	Moderate borehole transmissivity, fracture at 86' bgs
	5	91	106	High borehole transmissivity, fractures at 94', 97', and 100' bgs
	6	111	116	Moderate borehole transmissivity, high resistivity
	7	128	138	Fracture at 134' bgs
ERT-5	1	24	34	Shallowest interval, fracture at 32' bgs
	2	37	47	Fracture at 45' bgs, high resistivity
	3	50	60	Fractures at 54' and 58' bgs
	4	77	87	Fracture at 85' bgs
	5	93	98	Fracture at 97' bgs
	6	120	130	Fracture at 128' bgs, high resistivity

TABLE 2-1
OU3 RI MONITORING WELLS
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Well ID	FLUTE™ Well Port #	Sample Interval (ft bgs)		Construction note: Port/depth selection rationale
		Top	Bottom	
ERT-6	1	26	36	Fractures at 32' and 35' bgs, high resistivity
	2	75	85	High borehole transmissivity, fracture at 76' bgs
	3	93	103	Fracture at 98' bgs
	4	107	117	Moderate borehole transmissivity, fracture at 115' bgs
	5	128	138	Deepest interval, moderate resistivity
ERT-7	1	25	35	Shallowest interval, fractures at 26' and 33' bgs
	2	45	55	Fracture at 52' bgs
	3	65	75	High borehole transmissivity, fractures at 68' and 69' bgs
	4	100	110	High borehole transmissivity
	5	130	140	Deepest interval, fracture at 135' bgs
ERT-8	1	17	27	Shallowest interval, caliper log
	2	31	41	High borehole transmissivity
	3	44	54	High borehole transmissivity, caliper log
	4	57	62	High borehole transmissivity, caliper log
	5	87	97	Moderate borehole transmissivity, caliper log, inflection in resistivity
	6	107	112	Caliper log
	7	135	145	Deepest interval, caliper log
MW-13	1	18	28	Shallowest interval, moderate borehole transmissivity, fractures at 20' bgs
	2	35	45	Moderate borehole transmissivity, fracture at 38' bgs
	3	63	73	Moderate borehole transmissivity, inflection in resistivity
	4	95	105	Moderate borehole transmissivity, fractures at 98', 99', 100', 101' and 102' bgs
	5	115	125	Moderate borehole transmissivity, fracture at 123' bgs
	6	150	160	Moderate borehole transmissivity
	7	230	240	Deepest interval
MW-14S	1	30	35	Shallowest interval
	2	41	46	Inflection in resistivity
	3	55	60	Rock matrix results
	4	65	70	Deepest interval, moderate borehole transmissivity
MW-14D	1	80	85	Rock matrix results
	2	123	133	Rock matrix results
	3	199	209	Rock matrix results
MW-15S	1	30	40	Shallowest interval, moderate borehole transmissivity
	2	70	80	High borehole transmissivity, fracture at 75' bgs
MW-15D	1	125	135	Moderate borehole transmissivity, inflection in resistivity
	2	185	195	Fracture at 185' and 187' bgs
MW-16	1	20	30	Shallowest interval, fracture at 21' and 24' bgs
	2	40	50	Fractures at 44' and 49' bgs
	3	85	95	Fracture at 94' bgs
	4	108	118	Inflection in resistivity, temperature
	5	135	145	Rock matrix results
	6	170	180	Rock matrix results
	7	195	205	Caliper log, inflection in resistivity
MW-17	1	170	180	Moderate borehole transmissivity, fracture at 173' bgs
	2	205	215	High borehole transmissivity
	3	235	245	Deepest interval, inflection in resistivity
MW-18	1	160	170	Fracture at 163' bgs
	2	210	220	Deepest interval

TABLE 2-1
OU3 RI MONITORING WELLS
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Well ID	FLUTE™ Well Port #	Sample Interval (ft bgs)		Construction note: Port/depth selection rationale
		Top	Bottom	
MW-19	1	65	75	Shallowest interval; fracture at 65' bgs
	2	132	142	Inflection in resistivity, fracture at 141' bgs
	3	200	210	Fracture at 204' bgs
	4	257	267	Moderate borehole transmissivity
	5	367	377	Caliper log
	6	480	490	Inflection in resistivity, fractures at 481' and 488' bgs
	7	545	555	Deepest interval, caliper log, inflection in temperature
MW-20	1	25	35	Shallowest interval, moderate borehole transmissivity
	2	85	95	Moderate borehole transmissivity, fracture at 93' bgs
	3	125	135	Moderate borehole transmissivity
	4	175	185	Fracture at 177' bgs
	5	205	215	Moderate borehole transmissivity
	6	250	260	Fracture at 257' and 258' bgs
	7	297	307	High borehole transmissivity, fractures at 300' and 301' bgs
	8	355	365	Fracture at 363' bgs
MW-21	1	50	60	Moderate borehole transmissivity
	2	87	97	High borehole transmissivity
	3	150	160	Moderate borehole transmissivity, fracture at 155' bgs
	4	205	215	Moderate borehole transmissivity, fracture at 214' bgs
	5	260	270	Fracture at 266' bgs, intra-borehole flow velocity
	6	428	438	Moderate borehole transmissivity, inflection in resistivity
	7	485	495	Caliper log, fracture at 494' bgs
	8	505	515	Deepest interval, inflection in resistivity
MW-22	1	45	55	Moderate borehole transmissivity, inflection in resistivity, several fractures
	2	125	135	Caliper log
	3	210	220	Fractures at 213', 215', and 219' bgs
	4	305	315	Deepest interval, fracture at 310' bgs
MW-23	1	60	70	Fracture at 62' bgs, inflection in resistivity
	2	120	130	Fracture at 122' bgs, inflection in resistivity
	3	170	180	Fracture at 174' bgs
	4	226	236	Fractures at 234' and 235' bgs
	5	258	268	Moderate (relative) borehole transmissivity
	6	316	326	Fracture at 321' bgs
	7	350	360	Fracture at 353' bgs, inflection in resistivity
	8	406	416	Moderate (relative) borehole transmissivity
	9	444	454	Deepest interval, inflection in resistivity
Former Production Well	1	31	41	Shallowest interval, fracture at 37' bgs
	2	46	51	Moderate borehole transmissivity, several fractures
	3	100	110	Moderate borehole transmissivity, fractures at 105' and 106' bgs
	4	125	135	Fractures at 127' and 130' bgs
	5	180	190	Fractures at 185', 186', and 187' bgs
	6	200	205	Fracture at 202' bgs
	7	235	245	Fracture at 238' bgs
	8	268	278	Fractures at 269', 270', 273', and 274' bgs
	9	300	310	Deepest interval, fractures at 303', 305', and 309' bgs

TABLE 2-2
DATA SUMMARY AND SELECTION OF CHEMICALS OF CONCERN (COCs)
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Chemical	October 2009 Groundwater			March 2010 Groundwater			Combined Data Summary			Chemical Selected as COC? [Y/N]
	Frequency of Detection	Minimum Detected Concentration (µg/L)	Maximum Detected Concentration (µg/L)	Frequency of Detection	Minimum Detected Concentration (µg/L)	Maximum Detected Concentration (µg/L)	Frequency of Detection	Minimum Detected Concentration (µg/L)	Maximum Detected Concentration (µg/L)	
<i>Volatile Organic Compounds</i>										
1,1,1-Trichloroethane	9 / 128	0.27	0.92	11 / 128	0.17	1.0	20 / 256	0.17	1.0	N
1,1,2-Trichloro-1,2,2-trifluoroethane	1 / 128	1.2	1.2	2 / 128	1.3	2.2	3 / 256	1.2	2.2	N
1,1,2-Trichloroethane	3 / 128	0.46	1.8	23 / 128	0.27	120	26 / 256	0.27	120	Y
1,1-Dichloroethane	20 / 128	0.29	1.6	42 / 128	0.11	26	62 / 256	0.11	26	N
1,1-Dichloroethene	22 / 128	0.96	13	59 / 128	0.53	280	81 / 256	0.53	280	Y
1,2,3-Trichlorobenzene	10 / 127	0.53	84	26 / 126	0.12	280	36 / 253	0.12	280	N
1,2,4-Trichlorobenzene	16 / 127	0.39	340	28 / 126	0.10	1,600	44 / 253	0.10	1,600	Y
1,2-Dibromo-3-chloropropane	1 / 128	0.39	0.39	8 / 127	0.04	0.18	9 / 255	0.04	0.39	Y
1,2-Dibromoethane	0 / 128	--	--	1 / 128	0.01	0.01	1 / 256	0.01	0.01	N
1,2-Dichlorobenzene	4 / 127	0.57	3.7	21 / 126	0.15	56	25 / 253	0.15	56	N
1,2-Dichloroethane	6 / 128	0.46	0.79	21 / 128	0.22	15	27 / 256	0.22	15	Y
1,3-Dichlorobenzene	8 / 127	0.24	29	24 / 126	0.02	120	32 / 253	0.02	120	N
1,4-Dichlorobenzene	9 / 127	0.62	44	25 / 126	0.25	110	34 / 253	0.25	110	Y
2-Butanone	12 / 128	3.0	39	2 / 124	1.8	4.8	14 / 252	1.8	39	N
Acetone	26 / 128	2.9	530	22 / 126	0.82	78	48 / 254	0.82	530	N
Benzene	6 / 128	0.28	1.8	25 / 128	0.14	24	31 / 256	0.14	24	Y
Bromodichloromethane	17 / 128	0.28	1.7	4 / 127	0.25	0.48	21 / 255	0.25	1.7	Y
Bromoform	14 / 127	0.55	2.0	5 / 126	0.37	2.9	19 / 253	0.37	2.9	N
Carbon tetrachloride	3 / 128	0.36	0.46	6 / 128	0.25	0.72	9 / 256	0.25	0.72	N
Chlorobenzene	9 / 128	0.26	65	22 / 128	0.21	54	31 / 256	0.21	65	Y
Chloroform	37 / 128	0.48	150	53 / 128	0.26	19	90 / 256	0.26	150	Y
Chloromethane	0 / 128	--	--	2 / 128	0.62	1.3	2 / 256	0.62	1.3	N
cis-1,2-Dichloroethene	105 / 128	0.27	390,000	102 / 128	0.25	53,000	207 / 256	0.25	390,000	Y
Cyclohexane	2 / 128	2.2	2.3	9 / 128	0.23	13	11 / 256	0.23	13	N
Dibromochloromethane	11 / 128	0.26	0.61	7 / 128	0.21	1.2	18 / 256	0.21	1.2	Y
Ethylbenzene	0 / 128	--	--	5 / 128	0.43	20	5 / 256	0.43	20	N
Isopropylbenzene (cumene)	0 / 128	--	--	3 / 128	0.20	5.1	3 / 256	0.20	5.1	N
m,p-Xylene	0 / 128	--	--	5 / 128	0.41	15	5 / 256	0.41	15	N
Methyl acetate	1 / 128	3.4	3.4	0 / 128	--	--	1 / 256	3.4	3.4	N
Methyl tert-butyl ether	45 / 128	0.33	330	56 / 128	0.15	320	101 / 256	0.15	330	Y
Methylcyclohexane	0 / 128	--	--	11 / 127	0.14	42	11 / 255	0.14	42	N
Methylene chloride	1 / 128	1.4	1.4	20 / 128	0.23	7.0	21 / 256	0.23	7.0	Y
o-Xylene	1 / 128	0.33	0.33	7 / 128	0.99	85	8 / 256	0.33	85	N
Tetrachloroethene	37 / 128	0.26	1,600	69 / 128	0.12	110	106 / 256	0.12	1,600	Y
Toluene	60 / 128	0.16	78	71 / 128	0.13	86	131 / 256	0.13	86	N
trans-1,2-Dichloroethene	26 / 128	0.29	1,000	58 / 128	0.11	1,300	84 / 256	0.11	1,300	Y
Trichloroethene	115 / 128	0.29	170,000	106 / 128	0.28	23,000	221 / 256	0.28	170,000	Y
Trichlorofluoromethane	1 / 128	0.55	0.55	3 / 128	0.30	1.1	4 / 256	0.30	1.1	N
Vinyl chloride	25 / 128	0.71	710	39 / 128	0.36	860	64 / 256	0.36	860	Y

TABLE 2-2
DATA SUMMARY AND SELECTION OF CHEMICALS OF CONCERN (COCs)
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Chemical	October 2009 Groundwater			March 2010 Groundwater			Combined Data Summary			Chemical Selected as COC? [Y/N]
	Frequency of Detection	Minimum Detected Concentration (µg/L)	Maximum Detected Concentration (µg/L)	Frequency of Detection	Minimum Detected Concentration (µg/L)	Maximum Detected Concentration (µg/L)	Frequency of Detection	Minimum Detected Concentration (µg/L)	Maximum Detected Concentration (µg/L)	
Semi-Volatile Organic Compounds										
1,1'-Biphenyl	1 / 129	17	17	3 / 128	1.1	2.3	4 / 257	1.1	17	N
1,2,4,5-Tetrachlorobenzene	1 / 129	3.5	3.5	0 / 128	--	--	1 / 257	3.5	3.5	N
2,4-Dichlorophenol	1 / 129	5.3	5.3	0 / 128	--	--	1 / 257	5.3	5.3	N
2-Chlorophenol	1 / 128	2.6	2.6	0 / 128	--	--	1 / 256	2.6	2.6	N
2-Methylnaphthalene	2 / 129	0.18	2.2	4 / 128	0.12	0.27	6 / 257	0.12	2.2	N
Acenaphthene	2 / 129	0.28	0.39	3 / 128	0.13	0.34	5 / 257	0.13	0.39	N
Acetophenone	0 / 129	--	--	2 / 128	1.6	2.8	2 / 257	1.6	2.8	N
Anthracene	0 / 129	--	--	2 / 128	0.12	0.49	2 / 257	0.12	0.49	N
Benzaldehyde	2 / 128	4.2	7.2	0 / 128	--	--	2 / 256	4.2	7.2	N
Benzo(a)anthracene	0 / 129	--	--	3 / 128	0.08	1.7	3 / 257	0.08	1.7	Y
Benzo(a)pyrene	5 / 129	0.14	4.3	3 / 128	0.20	2.5	8 / 257	0.14	4.3	Y
Benzo(b)fluoranthene	2 / 128	2.1	3.0	8 / 128	0.08	2.1	10 / 256	0.08	3.0	Y
Benzo(g,h,i)perylene	2 / 128	2.1	2.6	11 / 128	0.09	2.4	13 / 256	0.09	2.6	N
Benzo(k)fluoranthene	3 / 129	1.3	3.5	7 / 128	0.09	2.0	10 / 257	0.09	3.5	Y
Bis(2-ethylhexyl)phthalate	25 / 129	2.1	26	5 / 128	1.2	3.7	30 / 257	1.2	26	Y
Caprolactam	34 / 129	2.0	95	1 / 128	2.5	2.5	35 / 257	2.0	95	N
Carbazole	0 / 159	--	--	1 / 128	0.54	0.54	1 / 287	0.54	0.54	N
Chrysene	0 / 159	--	--	4 / 128	0.09	1.7	4 / 287	0.09	1.7	N
Dibenzo(a,h)anthracene	0 / 127	--	--	31 / 128	0.07	5.5	31 / 255	0.07	5.5	Y
Diethylphthalate	1 / 129	41	41	1 / 128	1.7	1.7	2 / 257	1.7	41	N
Dimethylphthalate	1 / 129	11	11	0 / 128	--	--	1 / 257	11	11	N
Fluoranthene	0 / 129	--	--	3 / 128	0.38	2.9	3 / 257	0.38	2.9	N
Fluorene	1 / 129	0.56	0.56	2 / 128	0.17	0.29	3 / 257	0.17	0.56	N
Indeno(1,2,3-cd)pyrene	1 / 128	2.8	2.8	59 / 128	0.08	3.1	60 / 256	0.08	3.1	Y
Naphthalene	26 / 129	0.08	14	37 / 128	0.08	6.5	63 / 257	0.08	14	N
Pentachlorophenol	0 / 129	--	--	2 / 66	0.08	0.09	2 / 195	0.08	0.09	N
Phenanthrene	0 / 129	--	--	3 / 128	0.13	1.5	3 / 257	0.13	1.5	N
Phenol	2 / 128	2.4	3.0	4 / 128	1.8	4.3	6 / 256	1.8	4.3	N
Pyrene	1 / 129	0.91	0.91	3 / 128	0.31	2.3	4 / 257	0.31	2.3	N
Polychlorinated Biphenyls										
Aroclor-1016	1 / 129	0.13	0.13	15 / 128	0.06	30	16 / 257	0.06	30	Y
Aroclor-1248	21 / 122	0.12	7,300	0 / 128	--	--	21 / 250	0.12	7,300	Y
Aroclor-1254	33 / 127	0.06	5,600	38 / 128	0.03	190	71 / 255	0.03	5,600	Y
Pesticides										
4,4'-DDD	15 / 72	0.09	1,800	0 / 0	--	--	15 / 72	0.09	1,800	Y
4,4'-DDE	11 / 129	0.09	1,600	6 / 125	0.10	260	17 / 254	0.09	1,600	Y
4,4'-DDT	22 / 129	0.13	4,000	4 / 124	12	840	26 / 253	0.13	4,000	Y
alpha-BHC	5 / 129	0.12	0.33	8 / 128	0.09	68	13 / 257	0.09	68	Y
beta-BHC	9 / 129	0.06	680	0 / 128	--	--	9 / 257	0.06	680	Y

TABLE 2-2
DATA SUMMARY AND SELECTION OF CHEMICALS OF CONCERN (COCs)
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Chemical	October 2009 Groundwater			March 2010 Groundwater			Combined Data Summary			Chemical Selected as COC? [Y/N]
	Frequency of Detection	Minimum Detected Concentration (µg/L)	Maximum Detected Concentration (µg/L)	Frequency of Detection	Minimum Detected Concentration (µg/L)	Maximum Detected Concentration (µg/L)	Frequency of Detection	Minimum Detected Concentration (µg/L)	Maximum Detected Concentration (µg/L)	
delta-BHC	5 / 70	0.18	880	0 / 128	--	--	5 / 198	0.18	880	N
Dieldrin	2 / 128	0.18	0.33	6 / 125	0.19	350	8 / 253	0.18	350	Y
Endosulfan II	0 / 129	--	--	7 / 128	0.17	240	7 / 257	0.17	240	Y
Endosulfan sulfate	0 / 129	--	--	7 / 128	0.08	75	7 / 257	0.08	75	Y
Endrin	0 / 129	--	--	1 / 124	0.19	0.19	1 / 253	0.19	0.19	N
Endrin aldehyde	0 / 129	--	--	6 / 128	0.11	150	6 / 257	0.11	150	N
gamma-BHC (Lindane)	0 / 129	--	--	6 / 128	0.07	14	6 / 257	0.07	14	Y
gamma-Chlordane	0 / 129	--	--	13 / 128	0.06	370	13 / 257	0.06	370	Y
Heptachlor	10 / 129	0.06	300	6 / 128	0.37	120	16 / 257	0.06	300	Y
Heptachlor epoxide	2 / 129	0.20	2.6	0 / 128	--	--	2 / 257	0.20	2.6	Y
Methoxychlor	0 / 129	--	--	5 / 128	0.22	400	5 / 257	0.22	400	Y
<i>Inorganic Chemicals</i>										
Aluminum	41 / 128	27	6,210	34 / 128	71	2,710	75 / 256	27	6,210	Y
Antimony	4 / 129	2.0	3.2	1 / 128	3.5	3.5	5 / 257	2.0	3.5	N
Arsenic	129 / 129	0.87	829	128 / 128	0.68	428	257 / 257	0.68	829	Y
Barium	128 / 129	12	8,790	128 / 128	8.7	8,330	256 / 257	8.7	8,790	Y
Beryllium	3 / 129	0.069	0.20	2 / 128	0.23	0.45	5 / 257	0.069	0.45	N
Cadmium	16 / 129	0.04	4.6	8 / 128	0.30	17	24 / 257	0.04	17	Y
Calcium *	129 / 129	29,500	586,000	128 / 128	34,500	597,000	257 / 257	29,500	597,000	N
Chromium	44 / 129	0.11	78	53 / 128	0.36	97	97 / 257	0.11	97	Y
Cobalt	40 / 129	0.044	4.6	30 / 128	0.20	6.6	70 / 257	0.04	6.6	N
Copper	85 / 128	0.36	123	100 / 128	0.57	62	185 / 256	0.36	123	N
Cyanide	19 / 129	1.0	25	0 / 128	--	--	19 / 257	1.0	25	N
Iron	37 / 129	33.7	8,520	32 / 128	47	8,300	69 / 257	33.7	8,520	Y
Lead	110 / 129	0.71	21	124 / 128	0.25	33	234 / 257	0.25	33	Y
Magnesium *	129 / 129	1,160	130,000	128 / 128	4,210	135,000	257 / 257	1,160	135,000	N
Manganese	119 / 129	0.18	1,580	119 / 128	0.29	2,020	238 / 257	0.18	2,020	Y
Mercury	0 / 129	--	--	18 / 128	0.05	0.12	18 / 257	0.05	0.12	N
Nickel	95 / 110	0.72	13	95 / 128	0.21	18	190 / 238	0.21	18	N
Potassium *	95 / 129	791	26,700	66 / 128	1,660	27,800	161 / 257	791	27,800	N
Selenium	37 / 129	0.16	1.1	4 / 128	0.97	2.2	41 / 257	0.16	2.2	N
Silver	12 / 129	0.02	0.12	0 / 128	--	--	12 / 257	0.02	0.12	N
Sodium *	129 / 129	8,750	184,000	128 / 128	8,450	691,000	257 / 257	8,450	691,000	N
Vanadium	87 / 129	5.1	23	121 / 128	1.3	30	208 / 257	1.3	30	N
Zinc	129 / 129	6.2	125	128 / 128	2.5	187	257 / 257	2.5	187	N

TABLE 1
CHEMICAL-SPECIFIC ARARs
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Title	Citation	Description	ARAR or TBC	Comments
Federal				
Safe Drinking Water Act	40 CFR Part 141	Drinking water standards, expressed as maximum contaminant levels (MCLs), which apply to specific contaminants that have been determined to have an adverse impact on human health.	ARAR	Contaminant concentrations exceeding MCLs in drinking water may warrant corrective actions.
EPA Regional Screening Levels	http://www.epa.gov/region3/hwmd/risk/human/rb-concentration_table/Generic_Tables/pdf/master_sl_table_run_NOVEMBER2010.pdf	Provides concentrations for compounds and analytes based on their most recent risk assessment data.	TBC	May be used to screen contaminant concentrations to decide whether additional action is warranted.
State of New Jersey				
New Jersey Drinking Water Quality Act MCLs	NJAC 7:10-16	Rules that are promulgated to implement New Jersey's Safe Drinking Water Program. Standards are expressed as MCLs.	ARAR	Contaminant concentrations exceeding MCLs in drinking water may warrant corrective actions.
New Jersey Groundwater Quality Criteria	NJAC 7:9-16	The Ground Water Quality Standards (GWQS) establish the designated uses of the State's groundwaters, classify groundwaters based on those uses, and specify the water quality criteria to attain those designated uses. The ground water quality criteria are numerical values assigned to each constituent (pollutant) discharged to ground waters of the State. Ground water is classified according to its hydrogeologic characteristics and designated uses.	ARAR	Contaminant concentrations exceeding MCLs in groundwater may warrant corrective actions.

TABLE 3-2
PRELIMINARY GROUNDWATER NUMERICAL GOALS
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Chemical of Concern	CAS No.	NJDEP GW Quality Criteria (ug/L)	NJDEP PQL (ug/L)	Modified GW Quality Criteria (ug/L)	Federal MCLs (ug/L)	NJDEP Drinking Water MCLs (ug/L)	Preliminary Remediation Goal (ug/L)
Volatile Organic Compounds							
1,1,2-Trichloroethane	79-00-5	3	2	3	5	3	3
1,1-Dichloroethene	75-35-4	1	1	1	7	2	1
1,2,4-Trichlorobenzene	120-82-1	9	1	9	70	9	9
1,2-Dibromo-3-chloropropane	96-12-8	0.02	0.02	0.02	0.2	0.2	0.02
1,2-Dichloroethane	107-06-2	0.3	2	2	5	2	2
1,4-Dichlorobenzene	106-46-7	75	5	75	75	75	75
Benzene	71-43-2	0.2	1	1	5	1	1
Bromodichloromethane	75-27-4	0.6	1	1	80	NA	1
Chlorobenzene	108-90-7	50	1	50	100	50	50
Chloroform	67-66-3	70	1	70	80	NA	70
cis-1,2-Dichloroethene	156-59-2	70	1	70	70	70	70
Dibromochloromethane	124-48-1	0.4	1	1	80	NA	1
Methyl tert-butyl ether	1634-04-4	70	1	70	NA	70	70
Methylene chloride	75-09-2	3	1	3	5	3	3
Tetrachloroethene	127-18-4	0.4	1	1	5	1	1
trans-1,2-Dichloroethene	156-60-5	100	1	100	100	100	100
Trichloroethene	79-01-6	1	1	1	5	1	1
Vinyl chloride	75-01-4	0.08	1	1	2	2	1
Semi-Volatile Organic Compounds							
Benzo(a)anthracene	56-55-3	0.05	0.1	0.1	NA	NA	0.1
Benzo(a)pyrene	50-32-8	0.005	0.1	0.1	0.2	0.2	0.1
Benzo(b)fluoranthene	205-99-2	0.05	0.2	0.2	NA	NA	0.2
Benzo(k)fluoranthene	207-08-9	0.5	0.3	0.5	NA	NA	0.5
bis(2-Ethylhexyl)phthalate	117-81-7	2	3	3	6	6	3
Dibenzo(a,h)anthracene	53-70-3	0.005	0.3	0.3	NA	NA	0.3
Indeno(1,2,3-cd)pyrene	193-39-5	0.05	0.2	0.2	NA	NA	0.2
Polychlorinated Biphenyls and Dioxins							
Aroclor 1016**	12674-11-2	0.02	0.5	0.5	0.5	0.5	0.5
Aroclor 1248**	12672-29-6	0.02	0.5	0.5	0.5	0.5	0.5
Aroclor 1254**	11097-69-1	0.02	0.5	0.5	0.5	0.5	0.5
2,3,7,8-TCDD Toxic Equivalence (TEQ)	1746-01-6	0.0000002	0.00001	0.00001	0.00003	0.00003	0.00001
Pesticides							
4,4'-DDD	72-54-8	0.1	0.02	0.1	NA	NA	0.1
4,4'-DDE	72-55-9	0.1	0.01	0.1	NA	NA	0.1
4,4'-DDT	50-29-3	0.1	0.1	0.1	NA	NA	0.1
alpha-BHC	319-84-6	0.006	0.02	0.02	NA	NA	0.02
beta-BHC	319-85-7	0.02	0.04	0.04	NA	NA	0.04
Dieldrin	60-57-1	0.002	0.03	0.03	NA	NA	0.03
Endosulfan II	33213-65-9	40	0.04	40	NA	NA	40
Endosulfan sulfate	1031-07-8	40	0.02	40	NA	NA	40
gamma-BHC	58-89-9	0.03	0.02	0.03	0.2	0.2	0.03
gamma-Chlordane*	5103-74-2	0.01	0.5	0.5	2	0.5	0.5
Heptachlor	76-44-8	0.008	0.05	0.05	0.4	0.4	0.05
Heptachlor epoxide	1024-57-3	0.004	0.2	0.2	0.2	0.2	0.2
Methoxychlor	72-43-5	40	0.1	40	40	40	40
Inorganics							
Aluminum	7429-90-5	200	30	200	50-200	200	50
Arsenic	7440-38-2	0.02	3	3	10	5	3
Barium	7440-39-3	6,000	200	6,000	2,000	2,000	2,000
Cadmium	7440-43-9	4	0.5	4	5	5	4
Chromium	7440-47-3	70	1	70	100	100	70
Iron	7439-89-6	300	20	300	300	300	300
Lead	7439-92-1	5	5	5	15	NA	5
Manganese	7439-96-5	50	0.4	50	50	50	50

*Standards for gamma-Chlordane come from "Total" Chlordane standard that includes alpha- and gamma-Chlordane

**Aroclor standards are for "Total" PCB Aroclors which include all PCB Aroclors

TABLE 3-3
LOCATION-SPECIFIC ARARs
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Title	Citation	Description	ARAR or TBC	Comments
Federal				
Executive Order 11988 - Floodplain Management	40 CFR 6, Subpart A; 40 CFR 6.302	Activities taking place within floodplains must be performed to avoid adverse impacts and preserve beneficial values	TBC	Pertinent to activities that may occur within the floodplain.
Executive Order 11990 - Protection of Wetlands	40 CFR 6, Subpart A	Activities performed within wetlands areas must be done to avoid adverse impacts	TBC	Would be applicable to remediation activities impacting jurisdictional wetlands.
Policy on Floodplains and Wetlands Assessments for CERCLA Actions	OSWER 9280.0-02	Guidance for implementing executive orders 11988 and 11990.	TBC	Executive order implementation guidance.
Wetlands Protection at CERCLA site	OSWER 9280.0-03	Guidance document to be used to evaluate impacts to wetlands at Superfund sites	TBC	Requirements should be considered when evaluating impacts to jurisdictional wetlands.
National Historic Preservation Act	16 CFR 470	Established requirements for the identification and preservation of historic and cultural resources.	ARAR	Would be applicable to the management of historic or archaeological artifacts identified on the Site.
Endangered Species Act and Fish and Wildlife Coordination Act	16 CFR 661 and 16 U.S.C. 1531	Actions must be taken to conserve critical habitat in areas where there are endangered or threatened species.	ARAR	Requirements would be applicable if endangered or threatened species are identified on or adjacent to the Site.
Resource Conservation and Recovery Act (RCRA) Regulations - Location Standards	40 CFR 264.18	Regulates the design, construction, operation and maintenance of hazardous waste management facilities within the 100-year floodplain.	ARAR	Applicable for on-site treatment, storage or disposal of hazardous waste.
State of New Jersey				
Flood Hazard Area Regulations	NJAC 7:13	Regulates the placement of fill, grading, excavation and other disturbances within the defined flood hazard area/floodplain of rivers/streams.	ARAR	Applicable for Site activities occurring within the flood hazard area or floodplain of on-site rivers/streams.
Freshwater Wetlands Protection Act Rules	NJAC 7:7A	Regulates the disturbance or alteration of freshwater wetlands and their respective buffers.	ARAR	Applicable for Site activities disturbing freshwater wetlands and buffer areas.

TABLE 3-4

ACTION-SPECIFIC ARARs
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Action	Title	Citation	Description	ARAR or TBC	Comments
<i>Federal</i>					
Generation, Management, and Treatment of Hazardous Waste	Identification and Listing of Hazardous Wastes	40 CFR 261	Outlines criteria for determining if a solid waste is a hazardous waste and is subject to regulation under 40 CFR Parts 260 to 266.	ARAR	These regulations could apply for off-site disposal of contaminated groundwater or by-products of treatment.
	Hazardous Waste Determination	40 CFR 262.11	Generators must characterize their wastes to determine if the waste is hazardous by listing (40 CFR 261, Subpart D) by characteristic (40 CFR 261, Subpart C) or excluded from regulation (40 CFR 261.4)	ARAR	These regulations could apply for off-site disposal of contaminated groundwater or by-products of treatment.
	Manifesting	40 CFR 262, Subpart B	Generators must prepare a Hazardous Waste Manifest (EPA form 8700-22) for all off-site shipments of hazardous waste to disposal and/or treatment facilities.	ARAR	Would apply to all off-site shipments of hazardous waste.
	Recordkeeping	40 CFR 262.40	Generators must retain copies of all hazardous waste manifests used for off-site disposal.	ARAR	Generator must retain copies of waste manifests for a minimum period of three years after shipment date.
	Labeling and Marking	40 CFR 262 Subpart C	Specifies EPA marking, labeling and container requirements for off-site disposal of hazardous waste.	ARAR	Pre-transportation requirements for off-site shipments of hazardous wastes.
	Accumulation Limitations	40 CFR Part 262.34	Allows generators of hazardous waste to store and treat hazardous waste at the generation site for up to 90 days in tanks, containers, and containment buildings without having to obtain a RCRA hazardous waste permit.	ARAR	Hazardous waste may be stored for up to 90 days on-site without the need to meet storage permit substantive requirements.
	RCRA - Treatment, Storage and Disposal of Hazardous Waste	40 CFR 264/265	Specifies requirements for the operation of hazardous waste treatment, storage, and disposal facilities.	ARAR	Applicable for on-site hazardous waste treatment, storage, and disposal activities.
Transport of Hazardous Waste	USDOT Hazardous Materials Transportation Regulations	49 CFR 171-180	Established classification, packaging, and labeling requirements for shipments of hazardous materials.	ARAR	Applicable for the preparation of hazardous materials generated on-site for off-site shipment.
Air Emissions from a Point Source	National Ambient Air Quality Standards	40 CFR Part 50	Establishes ambient air quality standards for protection of public health.	ARAR	May be applicable in evaluating air impacts during remedial activities.

TABLE 3-4
ACTION-SPECIFIC ARARs
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Action	Title	Citation	Description	ARAR or TBC	Comments
Federal					
	New Source Review and Prevention of Significant Deterioration Requirements	40 CFR Part 52	New sources or modifications which emit greater than defined thresholds for listed pollutants must perform ambient impact analyses and install controls which meet best available control technology (BACT)	ARAR	Potentially applicable for certain remediation technologies and would require a comparison of potential emissions to the emission thresholds.
	National Emissions Standards for Hazardous Air Pollutants (NESHAP)	40 CFR Part 61; 40 CFR Part 63	Source-specific regulations which establish emissions standards for hazardous air pollutants	ARAR	Potentially applicable if emissions from remediation activities exceed thresholds for compliance.
	New Source Performance Standards	40 CFR Part 6	Source-specific regulations which establish testing, control monitoring and reporting requirements for new emissions sources.	ARAR	NSPS could be relevant and appropriate if regulated new sources of air emissions were to be established on site.
Land Disposal of Hazardous Waste	RCRA Subtitle C Land Disposal Restrictions	40 CFR Section 6901 40 CFR Part 268	Restricts land disposal of hazardous wastes that exceed specific criteria. Establishes Universal Treatment Standards to which hazardous waste must be treated prior to disposal.	ARAR	Potentially applicable if hazardous residuals are generated from groundwater treatment.
Discharges to Surface Water	Clean Water Act Effluent Guidelines and Standards; National Pollutant Discharge Elimination System (NPDES) Program	40 CFR Part 401 and 40 CFR Parts 122-125	Both on- and off-site discharges from CERCLA sites to surface waters are required to meet the substantive Clean Water Act limitations, monitoring requirements, and best management practices. NPDES permits are required to discharge treated water to a surface water.	ARAR	Applicable for discharges of groundwater to surface water bodies.
State of New Jersey					
Generation, Management, and Treatment of Hazardous Waste	Hazardous Waste Management Regulations	NJAC 7:26G	Requirements for the generation, accumulation, on-site management, and transportation of hazardous waste.	ARAR	Applicable for on-site management of hazardous waste.
	Treatment Works Approvals	NJAC 7:14A-22	Design and construction standards for wastewater treatment systems.	ARAR	Applicable for on-site treatment of groundwater.
Site Work	Soil Erosion and Sediment Control Act	NJSA 4:24	Requires the implementation of soil erosion and sediment control measures for activities disturbing over 5,000 square feet of land area.	ARAR	Applicable for site activities involving excavation, grading, or other soil disturbance activities.
Air Emissions from a Point Source	Air Quality Regulations	NJAC 7:27	Requirements applicable to air pollution sources.	ARAR	Applicable to the generation and emission of air pollutants.
General Site Investigation and Remediation	Technical Requirements for Site Remediation	NJAC 7:26E	Requirements for conducting site investigation and remediation in the state of New Jersey.	TBC	Applicable for Site activities disturbing freshwater wetlands and buffer areas.

TABLE 4-1
INITIAL TECHNOLOGY SCREENING FOR TECHNICAL IMPLEMENTABILITY
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
No Action	None	Not applicable	No action	X		Retain as baseline alternative
Institutional Controls	Administrative Restrictions	Groundwater use restrictions	Restrictions placed on installation of new supply wells and usage of existing groundwater supply wells. May be accomplished through a groundwater Classification Exception Area through NJDEP	X		Technically feasible. Public water supply wells maintained by Middlesex Water Company (Spring Lake Water Supply Wells) reportedly have not been used for water supply since the early 2000s.
Monitored Natural Attenuation	Natural Attenuation via Dilution, Adsorption, Dispersion, Biodegradation	Groundwater monitoring with analysis of biological and chemical indicators of attenuation processes	Establish a monitoring network and monitor contaminant concentrations and indicators of attenuation processes	X		Technically feasible. Natural attenuation of TCE via biodegradation is evident based on presence of cis-1,2-DCE in on-site and off-site wells. However, additional information is required to determine if biodegradation processes are completely mineralizing TCE in groundwater. PCBs, SVOCs, pesticides and dioxins/furans are not as amenable to natural attenuation via biodegradation. Inorganics also do not degrade biologically.

TABLE 4-1
INITIAL TECHNOLOGY SCREENING FOR TECHNICAL IMPLEMENTABILITY
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
In Situ Treatment	Thermal Treatment	Steam Enhanced Extraction (SEE)	Combination of steam injection and vacuum extraction	X		Potentially technically feasible if combined with other thermal treatment technology. Rock porosity and matrix diffusion limit the rate at which contaminants can be removed by vaporization. Hydraulic and pneumatic control, essential to successful steam injection and extraction, are difficult in fractured environment. Steam entering fractures typically gives up heat fairly quickly; large heat losses along fractures lead to rapid condensation and short travel distances of steam, limiting treatment effectiveness. However, this is the cheapest form of thermal treatment and may provide benefits if combined with other thermal technology.
		Electrical Resistance Heating (ERH)	Uses application of 3- or 6-phase electrical power and resistivity of soil particles to heat subsurface	X		Potentially technically feasible for organic contaminants. Does not rely on fluid movement to deliver heat.
		Dynamic Underground Stripping (DUS) / Hydrous Pyrolysis Oxidation (HPO)	Steam and oxygen are injected in paired wells below the water table to build a		X	Combination of SEE (presumably will flow preferentially through fractures), ERH (to heat up the rock matrix), and injection of oxygen to

TABLE 4-1
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General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
			heated, oxygenated zone at the periphery of the contaminated area to drive contaminants to centrally located extraction wells. Electrical energy applied to less permeable strata.			oxidize contaminants. Only known vendor is no longer in business. No case studies for fractured rock.
		Thermal Conduction Heating (TCH), also known as In Situ Thermal Desorption (ISTD)	Install heater wells that have operating temperatures as high as 800°C and extract vapor.	X		Potentially technically feasible for organic contaminants. Not as sensitive to geological heterogeneities and to electrical conductivity as other technologies.
	Biological Treatment	Enhanced Reductive Dechlorination (biostimulation only)	Injection of carbon substrate to promote anaerobic conditions and foster growth of dechlorinating bacteria.	X		Potentially technically feasible primarily for chlorinated ethenes. Naturally occurring biodegradation evident at several on-site monitoring locations. This technology has been used in fractured rock to treat chlorinated solvents.
		Enhanced Reductive Dechlorination (biostimulation and bioaugmentation)	Injection of a microbial culture known to perform complete dechlorination of targeted compounds	X		Potentially technically feasible primarily for chlorinated ethenes. This technology has been used in fractured rock to treat chlorinated solvents.

TABLE 4-1
INITIAL TECHNOLOGY SCREENING FOR TECHNICAL IMPLEMENTABILITY
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

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				Retain	Reject	
	In Situ Chemical Oxidation	Permanganate	Injection of sodium permanganate or potassium permanganate.	X		Potentially technically feasible primarily for chlorinated ethenes. Permanganate has the potential for density-driven diffusion into rock to treat contaminants in rock pore water.
		Catalyzed hydrogen peroxide (CHP)	Injection of hydrogen peroxide and a catalyst (typically ferrous sulfate) to produce hydroxyl free radicals.		X	Not technically feasible. Difficult to catalyze the hydrogen peroxide in fractured rock environment since catalyst and peroxide injected separately. CHP is too short-lived to diffuse into rock matrix or reach dead-end fractures.
		Activated persulfate	Injection of persulfate into subsurface. The persulfate is activated via addition of a base, addition of a ferrous salt, or addition of heat to produce the sulfate free radical.	X		Potentially technically feasible. Persulfate typically activated prior to injection. It is more long-lived than CHP, but less than permanganate.
	Permeable Reactive Barriers	Zero-Valent Iron	Emplace zero-valent iron into the aquifer perpendicular to groundwater flow		X	Not technically feasible. Not feasible to emplace stationary vertical barrier composed of reactive media in deep fractured rock. Many pathways for groundwater that might circumvent the iron.
		Nano-Scale Iron	Inject nano-scale iron into fractures		X	Not technically feasible. Cannot deliver iron to low permeability

TABLE 4-1
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General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
						zones where contaminants reside. Difficult to ensure that iron stays in place for a long enough period (i.e., does not migrate out of treatment zone) to treat contamination in fracture water and contaminant mass back-diffusing from the matrix.
	Enhanced Desorption and Treatment	Surfactant Enhanced Aquifer Remediation (SEAR)	Inject surfactant solution to solubilize and/or mobilize DNAPL. Typically followed by a water flush.		X	Not technically feasible. Difficult to control flow of surfactant and to extract mobilized contaminants in fractured rock geology. Potential for further mobilizing contamination.
		Co-Solvent Flooding	Injection and extraction of cosolvents, such as alcohol, to solubilize and or mobilize DNAPL. Similar to SEAR in design and implementation.		X	Not technically feasible. Difficult to control flow of co-solvents and to extract mobilized contaminants in fractured rock geology. Potential for further mobilizing contamination.
		Air sparging	Inject air into aquifer to gasify contaminants and mobilize gas phase from groundwater to surface. May need additional gas phase treatment at surface.		X	Not technically feasible. Fractures create preferential flowpaths for air. Not effective at removing contaminants from smaller fractures or rock matrix.

TABLE 4-1
INITIAL TECHNOLOGY SCREENING FOR TECHNICAL IMPLEMENTABILITY
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General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
Containment	Hydraulic Control	Extraction wells	Single or multiple vertical wells to extract groundwater using pumps	X		Technically feasible. Contain groundwater by manipulating the gradient around site.
		Interceptor trenches	Groundwater collection in a closed, permeable trench from which groundwater is extracted using pumps		X	Not technically feasible. Very difficult to implement because it requires deep trenching through rock.
	Vertical barrier	Slurry wall	Trench around areas of contamination and backfill with a low-permeability soil-bentonite or cement-bentonite slurry		X	Not technically feasible for bedrock aquifer
		Sheet piling	Drive steel sheet pile around areas of contamination		X	Not technically feasible for bedrock aquifer
	Capping	Multimedia cap	Low-permeability clay and synthetic membrane covered by soil over areas of contamination to minimize groundwater recharge		X	Not applicable for OU3. Surface recharge is not a significant factor controlling groundwater movement at OU3.
		Asphalt or concrete cap	Installation of a layer of asphalt or installation of a		X	The remedial action currently underway for OU2 already includes installation of an asphalt cap over

TABLE 4-1
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General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
			concrete slab over areas of contamination to minimize groundwater recharge			the majority of the former CDE facility. Therefore, this option is not required for OU3.
Ex Situ Treatment / Discharge	Biological Treatment	Aerobic bioreactor	Degradation of organics using microorganisms in an aerobic environment	X		Technically feasible for certain organics. Chlorinated solvents and PCBs may be biodegraded aerobically.
	Physical /Chemical Treatment	Carbon adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column	X		Technically feasible. Chlorinated solvents and PCBs as well as dioxin/furans, pesticides, and SVOCs may be removed by carbon adsorption. Arsenic, especially As(III), may also be removed by carbon adsorption.
		Chemical / UV oxidation	Chemical oxidation with or without enhancement with ultraviolet radiation	X		Technically feasible. Chlorinated solvents, PCBs, SVOCs, pesticides, and dioxins/furans may be treated by chemical / UV oxidation
		Ion Exchange	Water is passed through a resin bed where ions are exchanged between resin and water	X		Technically feasible. Lead and arsenic (and potentially other inorganics) may be removed using ion exchange resins.

TABLE 4-1
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South Plainfield, New Jersey

General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
		Precipitation / Co-Precipitation	Use of pH adjustment, addition of a chemical precipitant, and flocculation to alter chemical equilibria to reduce solubility of contaminants	X		Technically feasible. Lead and arsenic (and potentially other inorganics) may be removed from water via precipitation to form a solid, which is then removed by filtration or clarification.
		Air stripping	Aerate water to induce volatilization of contaminants in a packed column	X		Technically feasible only for volatile organic compounds. However, may be used in treatment train in conjunction with other processes to treat commingled non-volatile contaminants.
		Filtration (reverse osmosis, microfiltration, media filtration)	Separation processes to remove particles from solution	X		Technically feasible. Filtration may be needed to remove PCBs and pesticides associated with colloid particles (e.g., as part of a treatment train, prior to activated carbon treatment) or to remove precipitated inorganics.
	Off-Site Treatment	POTW	Extracted groundwater discharged to local POTW for treatment		X	Not technically feasible. It is unlikely that POTW will accept water containing high levels of solvents, PCBs, pesticides, and SVOCs without pretreatment.

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General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
		RCRA TSDF	Extracted groundwater transported to licensed RCRA facility for treatment and/or disposal		X	Not technically feasible to transport volumes of water likely to be generated for hydraulic capture/containment.
	Discharge of treated water	Discharge to surface water	Discharge to nearby stream (Bound Brook)	X		Technically feasible if meeting discharge criteria (water quality and volume criteria) and NJDEP discharge permit.
		Discharge to POTW	Treated water discharged to local POTW	X		Technically feasible if treatment attains discharge criteria.
		Infiltration Basin or Gallery	Treated water discharged to infiltration basin or gallery		X	Not technically feasible to construct a basin or gallery at or near the CDE facility because bedrock is shallow.
		Deep well injection	Injection of treated water at the site via deep injection wells	X		Potentially technically feasible. Would need an underground injection permit from NJDEP.

TABLE 4-2
EVALUATION OF TECHNOLOGIES AND PROCESS OPTIONS
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

General Response Action	Technology Class	Process Option	Description/Definition	Effectiveness	Implementability	Relative Cost	Evaluation Action	
							Retain	Reject
No Action	None	None	Not applicable	<ul style="list-style-type: none"> - Not effective in reducing contamination. - Does not meet RAOs. 	<ul style="list-style-type: none"> - Easily implemented. - Alternative required by NCP. 	Low	X	
Institutional Controls	Administrative Restrictions	Groundwater use restrictions	<ul style="list-style-type: none"> - Restrictions placed on installation and usage of new groundwater wells and usage of existing wells. - May be accomplished through a groundwater Classification Exception Area through NJDEP 	<ul style="list-style-type: none"> - Effectiveness depends on continued implementation. - Does not reduce contamination. 	<ul style="list-style-type: none"> - Requires NJDEP approval. - May be used in conjunction with other technologies. 	Low	X	
Monitored Natural Attenuation	Natural attenuation via dilution, adsorption, dispersion, biodegradation	Groundwater monitoring with analysis of biological and chemical indicators of attenuation processes	<ul style="list-style-type: none"> - Establish a monitoring network and monitor contaminants concentrations and indicators of attenuation processes 	<ul style="list-style-type: none"> - Most effective in combination with source removal / reduction. - Chlorinated ethenes are more amenable to biodegradation than PCBs, pesticides, SVOCs and dioxins/furans. However, PCBs, pesticides, SVOCs, and dioxins/furans may be attenuated via dispersion, adsorption, and dilution mechanisms. - Inorganics do not biodegrade; however, they may attenuate via dispersion, adsorption, and dilution. - Will not meet RAOs in the source area within a reasonable time frame. Uncertain whether RAOs will be achieved in plume area over reasonable time frame. 	<ul style="list-style-type: none"> - Easily implemented. - May be used as a stand-alone technology, or applied after effectiveness of active treatment diminishes. - Typically has a long period of performance. 	Low capital, moderate O&M	X	
In Situ Treatment	Thermal Treatment	Steam Enhanced Extraction (SEE)	<ul style="list-style-type: none"> - Uses alternating steam injection and vacuum extraction - Increases vapor pressure and volatilization rates of organic compounds. Also reduces viscosity and residual saturation of SVOCs and non-volatile compounds, resulting in greater mobility. 	<ul style="list-style-type: none"> - Limited to removal of contaminants in the fracture water only. - Most effective for low-boiling-point compounds. - Small fracture apertures and infrequent occurrence of fractures limit achievable rate of steam injection. - Hydraulic and pneumatic control are difficult in a fracture environment. - Limited effectiveness for inorganics. - May enhance chlorinated ethene biodegradation. 	<ul style="list-style-type: none"> - Has been used at least at one fractured rock site with mixed success. - May be implemented in conjunction with TCH or ERH, especially in portions of OU3 where there is a lot of flow (e.g., at productive fractures about 70 feet below ground surface near MW-14). 	High capital, high O&M	X (potentially in conjunction with other thermal treatment technology)	

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General Response Action	Technology Class	Process Option	Description/Definition	Effectiveness	Implementability	Relative Cost	Evaluation Action	
							Retain	Reject
		Electrical Resistance Heating (ERH)	<ul style="list-style-type: none"> - Uses application of 3- or 6-phase electrical power and resistivity of soil particles to heat subsurface - Delivered to the subsurface by buried electrodes - Electrical current flows from each electrode to adjacent out-of-phase electrodes - Results in generation of steam - Not dependent on fluid transfer like steam technologies 	<ul style="list-style-type: none"> - ERH is limited by the electrical resistivity of the rock. Rock with low porosity, and thus low water content, has higher electrical resistance. - Most effective for low-boiling-point compounds. - Limited effectiveness for PCBs, pesticides, SVOCs, and dioxins/furans, mainly via removal of carrier fluids (i.e., solvent NAPL). - Limited effectiveness for inorganics. - May enhance chlorinated ethene biodegradation. 	<ul style="list-style-type: none"> - Would need to do a site-specific evaluation to determine acceptable electrode separations. - It is possible to extract fluids from ERH heating boreholes. This keeps fluids moving inward towards the heated zone during operations and reduces risk of spreading contaminants. - Limited case study information for fractured rock; however, has been used at DNAPL sites. 	High capital, high O&M	X	
		Thermal Conduction Heating (TCH), also known as In Situ Thermal Desorption (ISTD)	<ul style="list-style-type: none"> - Applies heat by a combination of thermal conduction and vacuum - Heats soil to temperatures above boiling point of water - The dominant removal mechanism for VOC DNAPL is vaporization - In fractured rock systems, boiling of fluids in the fractures and the matrix leads to steam formation, which sweeps out of the rock towards locations with low pressure. - By using each heater boring for extraction, can minimize spread of contaminants 	<ul style="list-style-type: none"> - Applicable to high boiling point contaminants, including PCBs, pesticides, SVOCs, and dioxins/furans – but more difficult in saturated areas, because would need to boil off water first (i.e., PCBs, pesticides, SVOCs, and dioxins/furans have higher boiling point than water). - May enhance chlorinated ethene biodegradation. - Has been performed in fractured rock for chlorinated solvents (Heron et al., 2008). 	<ul style="list-style-type: none"> - More easily implementable in low to moderate flow systems. - Limited when dewatering is difficult. 	High capital, high O&M. Costs increase with groundwater dewatering and treatment.	X	

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General Response Action	Technology Class	Process Option	Description/Definition	Effectiveness	Implementability	Relative Cost	Evaluation Action	
							Retain	Reject
	In Situ Bioremediation	Enhanced Reductive Dechlorination (biostimulation only)	<ul style="list-style-type: none"> - Injection of organic substrate, which releases hydrogen (electron donor) upon fermentation - Enhances reductive dechlorination of chlorinated solvents - Wide variety of carbon substrates – soluble substrates (lactate, molasses), viscous fluids (HRC®, vegetable oils), low-viscosity fluids (emulsified vegetable oils), solid substrates (mulch, compost) - Facilitates desorption of NAPL via development of steep concentration gradients and release of biosurfactants 	<ul style="list-style-type: none"> - Effectiveness for treating PCBs, pesticides, SVOCs, and dioxins/furans is unknown. - Not effective for inorganics. - Mixed results from site microcosm studies. Results indicate that certain locations (14S-04, 14D-01, 16-05, 16-07) have bacterial populations that convert TCE to ethene when stimulated. Other locations (14S-01, 14S-02) may also contain these populations based on detection of ethene and vinyl chloride at these monitoring locations. - Limitations in microbial populations create the potential for incomplete degradation and the buildup of cis-DCE or vinyl chloride (e.g., microcosm bottles from sample ports 14S-01, 14S-02, 16-02, 16-03, 16-04, 16-07) 	<ul style="list-style-type: none"> - May be difficult to distribute carbon substrate throughout fracture system - Potential for fouling of injection wells. - Generally applies to dissolved phase (although may enhance desorption / dissolution of NAPL). - May be used in combination with other treatment methods as part of an overall site strategy. - May be difficult to distribute throughout the fracture system. - Typically requires multiple applications, or injection events (e.g., quarterly or semi-annually). 	Moderate capital cost and moderate O&M cost	X	
		Enhanced Reductive Dechlorination (biostimulation and bioaugmentation)	<ul style="list-style-type: none"> - Injection of a microbial culture (either non-native, or enriched native culture) known to perform complete dechlorination of targeted compounds - Bioaugmentation may be used at a site when the presence of an appropriate population of microbial dechlorinators is not present, or does not exist in sufficient numbers to achieve remediation criteria in a reasonable time frame - Typically performed in concert with addition of carbon substrate (i.e., biostimulation) - Facilitates desorption of NAPL via development of steep concentration gradients and release of biosurfactants 	<ul style="list-style-type: none"> - May be able to enrich existing dechlorinating bacteria (e.g., at locations shown in the microcosm studies to have these populations) and reinject. - May be able to engineer cultures capable of degrading PCBs, pesticides, SVOCs, and/or dioxins/furans; however, many compounds in these contaminant classes are resistant to biological degradation. - Not effective for treating inorganics. - Effectiveness depends on how well the bacterial cultures adapt and grow. This technology has been shown to be effective at many other sites; however, experience in fractured bedrock DNAPL sites is limited. 	<ul style="list-style-type: none"> - May be difficult to ensure that engineered cultures are not suppressed by competing native microbial populations, and may be difficult to distribute the engineered culture(s) uniformly throughout treatment zone in fractured rock. - Potential for fouling of injection wells. - There is an additional cost at the outset to develop appropriate site-specific cultures, and time period for this work is typically 4 to 8 months. However, overall cost increase is typically not significant when compared to overall project costs for biostimulation alone. - May be difficult to distribute throughout the fracture system. - Typically requires multiple applications, or injection events (e.g., quarterly or semi-annually). 	Moderate capital cost and moderate O&M cost (but higher cost than biostimulation alone)	X	

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General Response Action	Technology Class	Process Option	Description/Definition	Effectiveness	Implementability	Relative Cost	Evaluation Action	
							Retain	Reject
	In Situ Chemical Oxidation				- May be used in combination with other treatment methods as part of an overall site strategy.			
		Permanganate (potassium or sodium)	<ul style="list-style-type: none"> - Injection of sodium permanganate or potassium permanganate. - Delivery methods include direct injection and oxidant recirculation. - Results in direct oxidation of organic contaminants. 	<ul style="list-style-type: none"> - Effectiveness is limited by mass transfer limitations (i.e., matrix diffusion of contaminants in the rock). However, permanganate has the potential for density-driven diffusion into the rock matrix to treat contaminants dissolved in rock pore water. - Rock oxidant demand (ROD) will need to be determined. If ROD is too high, then ISCO will not be effective. - Permanganate is not effective for oxidizing PCBs, pesticides, most SVOCs, and dioxins/furans. - Not effective for inorganics; however, will oxidize arsenite to arsenate, which is less toxic. - Reaction at DNAPL interface may result in formation of manganese dioxide 'coating' around DNAPL particles. - Recent case studies indicate that this process option is less effective for DNAPL sites, especially in fractured rock. 	<ul style="list-style-type: none"> - May be difficult to distribute permanganate throughout the fracture system. - Typically requires multiple applications, or injection events (e.g., quarterly or semi-annually). 	Medium capital cost and medium O&M cost (cost increases when multiple treatments are required)	X	
		Activated persulfate	<ul style="list-style-type: none"> - Involves injection of persulfate into the subsurface. The persulfate would be activated to produce the sulfate free radicals. Persulfate can be activated via addition of a base, addition of a ferrous salt, or addition of heat. - Results in direct oxidation of organic contaminants - Delivery method is typically direct injection 	<ul style="list-style-type: none"> - Effectiveness is limited by mass transfer limitations (i.e., matrix diffusion of contaminants in the rock). Persulfate is shorter-lived than permanganate. Therefore, it may not be as likely to be active over the long time-frames required for diffusion into the rock matrix as permanganate. - May treat PCBs, pesticides, certain SVOCs, and dioxins/ furans (only if activated with high pH or heat) - Not effective for inorganics; however, will oxidize arsenite to arsenate, which is less toxic. - Rock oxidant demand will need to be determined. If ROD is too high, then ISCO will not be effective. 	<ul style="list-style-type: none"> - May be difficult to distribute persulfate throughout the fracture system. - Typically requires multiple applications, or injection events (e.g., quarterly or semi-annually). 	Medium capital cost and medium O&M cost (cost increases when multiple treatments are required)	X	

TABLE 4-2
EVALUATION OF TECHNOLOGIES AND PROCESS OPTIONS
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General Response Action	Technology Class	Process Option	Description/Definition	Effectiveness	Implementability	Relative Cost	Evaluation Action	
							Retain	Reject
				<ul style="list-style-type: none"> - There are very few (if any) case studies of persulfate application in fractured rock, so anticipated performance would need to be extrapolated from case studies of activated persulfate in porous media, and/or case studies of other oxidants in fractured rock. - Recent case studies indicate that this process option is less effective for DNAPL sites, especially in fractured rock. 				
Containment	Hydraulic Control	Extraction Wells	<ul style="list-style-type: none"> - Single or multiple vertical wells to extract groundwater using pumps. 	<ul style="list-style-type: none"> - Most effective for homogenous aquifers with moderate transmissivity and dissolved, mobile compounds; but has been applied successfully in fractured rock settings. - Effectiveness depends on optimizing extract well placement and groundwater extraction rates. - Goal is to reduce contaminant migration. 	<ul style="list-style-type: none"> - Will need to be implemented in conjunction with a treatment system for the groundwater that is captured. - Long-term operation required. 	Moderate to high capital cost (including ex situ treatment components). Moderate to high O&M cost which depends on complexity of treatment train and cost of discharge options.	X	
Ex Situ Treatment / Discharge	Biological Treatment	Aerobic Bioreactor	<ul style="list-style-type: none"> - Degradation of organics using microorganisms in an aerobic environment. - Can use fixed film bioreactors (bacteria are attached to a solid support medium) or suspended growth reactors. 	<ul style="list-style-type: none"> - Cis-DCE and vinyl chloride may be degraded aerobically. - Lower molecular weight PCBs, SVOCs and dioxins/furans may be degraded aerobically. - Not effective for inorganic contaminants. 	<ul style="list-style-type: none"> - May need to be performed in conjunction with anaerobic treatment as the first step. - Will likely require significant up-front effort for a pilot study to optimize design parameters. - Potentially more rigorous O&M as compared to physical /chemical options, since microbes are more susceptible to fluctuations in influent water chemistry and contaminant concentrations. 	Moderate capital cost. Moderate to high O&M costs.	X (as part of treatment train)	
		Anaerobic Bioreactor	<ul style="list-style-type: none"> - Degradation of organics using microorganisms in an anaerobic environment. - Can use fixed film bioreactors (bacteria are attached to a solid 	<ul style="list-style-type: none"> - Anaerobic dechlorination of PCBs and certain dioxins/furans removes chlorines from highly chlorinated congeners, and thus reduces their toxicity and increases their aerobic biodegradability. 	<ul style="list-style-type: none"> - May need to be performed in conjunction with aerobic treatment as the second step. - Will likely require significant up-front effort for a pilot study to 	Moderate capital cost. Moderate to high O&M costs.	X (as part of treatment train)	

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General Response Action	Technology Class	Process Option	Description/Definition	Effectiveness	Implementability	Relative Cost	Evaluation Action	
							Retain	Reject
			support medium) or suspended growth reactors.	<ul style="list-style-type: none"> - PCE and TCE are dechlorinated most effectively under anaerobic conditions. - Not effective for inorganic contaminants. 	<ul style="list-style-type: none"> optimize design parameters. - Potentially more rigorous O&M as compared to physical /chemical options, since microbes are more susceptible to fluctuations in influent water chemistry and contaminant concentrations. 			
	Physical / Chemical Treatment	Carbon Adsorption	- Adsorption of contaminants onto activated carbon by passing water through a carbon column.	<ul style="list-style-type: none"> - Most effective when treating water streams that contain organic contaminants at concentrations lower than 10 mg/L. - May be used as a polishing step in conjunction with other treatment technologies. - May be effective for PCB, pesticide, SVOC, and dioxin/furan removal in conjunction with filtration. 	<ul style="list-style-type: none"> - Readily implementable. However, will likely require upstream and downstream filtration to remove colloidal materials associated with the PCBs and pesticides. 	Moderate capital cost. Moderate to high O&M costs.	X (as part of treatment train)	
		Adsorption with non-carbon media	<ul style="list-style-type: none"> - Adsorption of contaminants (primarily inorganics) by passing water through a fixed bed of media (e.g., activated alumina, greensand filtration, proprietary media). - When adsorption sites become filled, the media must be regenerated or disposed of and replaced with new media. 	<ul style="list-style-type: none"> - Activated alumina is the most common adsorbent to remove arsenic from water. Can reduce arsenic concentrations to less than 50 ug/L. - Adsorption is typically more effective at removing As(V) than As(III). - Lead may also be removed by activated alumina. Effectiveness is closely linked to the pH (most effective at pH 5.5-6.0). - May also be effective for other inorganic COPCs. 	<ul style="list-style-type: none"> - Non-carbon adsorptive media to remove arsenic and lead from water are readily available commercially. - In addition to activated alumina, other types of media include greensand filtration (KMnO4-coated glauconite), copper-zinc granules, surfactant-modified zeolite, granular ferric hydroxide, or proprietary media. - Implementation is influenced by fouling of the media (i.e., may need to design backwash system), rate of groundwater flow, and groundwater pH (may need pretreatment or post-treatment). 	Moderate capital cost. Moderate to high O&M costs (depending on cost of media)	X (as part of treatment train)	
		Chemical / UV Oxidation	- Chemical oxidation with or without enhancement with ultraviolet radiation.	<ul style="list-style-type: none"> - Destroys organic contaminants as part of the treatment process rather than transferring them to other media. - Well-established, effective technology for organics. - Does not treat inorganics; however, may be used to oxidize As(III) to As (V) as pretreatment for other process. 	<ul style="list-style-type: none"> - Readily implementable. However, may need a treatability study to establish appropriate dosages and to determine whether UV treatment is needed, especially for PCBs, pesticides, SVOCs, and dioxins/furans. 	Moderate capital cost. Moderate to high O&M cost.	X (as part of treatment train)	

TABLE 4-2
EVALUATION OF TECHNOLOGIES AND PROCESS OPTIONS
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

General Response Action	Technology Class	Process Option	Description/Definition	Effectiveness	Implementability	Relative Cost	Evaluation Action	
							Retain	Reject
		Ion Exchange	<ul style="list-style-type: none"> - Water is passed through a resin bed where ions are exchanged between resin and water. - Need to match the appropriate resin to the contaminant being removed. - Process is often preceded by filtration to remove suspended solids and other compounds that can foul the resins. 	<ul style="list-style-type: none"> - Used more commonly for arsenic removal than for lead removal. - Only effective for removal of As(V). If As(III) is present, then will need to have an oxidation step before the ion exchange treatment to oxidize As(III) to As(V). - Typically reduces arsenic concentrations to less than 50 ug/L (and in some cases to less than 10 ug/L). 	<ul style="list-style-type: none"> - Readily implementable. However, may need a treatability study to determine loading rate and achievable effluent concentrations. - Probably will need different resins for different types of inorganic contaminants; therefore, may need multiple treatment vessels. - Typically need to regenerate the resins, which involves backwashing, regeneration with ion solution, and final rinsing to remove the regeneration solution. This results in a separate waste stream that needs to be handled. 	Moderate capital cost. Moderate to high O&M cost.	X (as part of treatment train)	
		Precipitation / Co-precipitation	<ul style="list-style-type: none"> - Use of pH adjustment, addition of a chemical precipitant, and flocculation to alter chemical equilibria to reduce solubility of contaminants. - In co-precipitation, the target contaminant may be dissolved or in a colloidal or suspended form. Dissolved contaminants do not precipitate, but are adsorbed onto another species that is precipitated. Colloidal or suspended contaminants become enmeshed with other precipitated species, or are removed through processes such as coagulation and flocculation. - Many processes to remove inorganics from solution involve a combination of precipitation and co-precipitation. 	<ul style="list-style-type: none"> - Most frequently used method to remove inorganics from solution. - Can reduce arsenic to concentrations less than 50 ug/L (and in some cases to less than 10 ug/L). - Effectiveness depends on the valence state of the inorganic contaminant - The effectiveness of precipitation / co-precipitation relies on complex chemistry and depends upon a variety of factors, including the speciation of the inorganic contaminant, the chemical precipitants used and their concentrations, the pH of the water, and the presence of other chemicals in the water to be treated. 	<ul style="list-style-type: none"> - This process is commonly used in drinking water and industrial wastewater plants; therefore, the materials needed to implement this process are readily available. - The process usually generates a sludge residual, which typically requires treatment such as dewatering and subsequent disposal. Some sludge can be hazardous waste and requires additional treatment such as solidification / stabilization prior to disposal. 	Moderate capital cost. Moderate to high O&M costs (depending on types and dosage of chemicals and sludge disposal)	X (as part of treatment train)	
		Air Stripping	<ul style="list-style-type: none"> - Aerate water to induce volatilization of contaminants in a packed column. 	<ul style="list-style-type: none"> - Very effective for VOCs with high Henry's Law constants. But high concentrations (>200 mg/L) may hinder effectiveness. - Not effective for PCBs, pesticides, most SVOCs, or dioxins/furans. 	<ul style="list-style-type: none"> - Readily implementable. However, may need a treatability study to determine design parameters. - May require off-gas treatment, which may be achieved using (1) vapor-phase carbon adsorption; (2) 	Moderate capital cost. Low to high O&M cost depending on whether off-	X (as part of treatment train)	

TABLE 4-2
EVALUATION OF TECHNOLOGIES AND PROCESS OPTIONS
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

General Response Action	Technology Class	Process Option	Description/Definition	Effectiveness	Implementability	Relative Cost	Evaluation Action	
							Retain	Reject
				- Not effective for inorganic contaminants.	catalytic oxidation; or (3) thermal-oxidation treatment.	gas treatment is required.		
		Filtration (reverse osmosis, microfiltration, media filtration)	- Separation processes to remove particles from solution.	- Typically used as a pretreatment or post-treatment step for other treatment technologies. - Effectiveness depends on selecting the appropriate process and appropriate filtration medium, and proper O&M.	- Readily implementable. May require a treatability study to determine appropriate media types, especially for removal of PCB colloids.	Moderate capital cost. Moderate to high O&M cost.	X (as part of treatment train)	
	Discharge of Treated Water	Discharge to surface water	- Discharge to nearby stream (Bound Brook).	- Effective and reliable means of discharging water.	- Discharge would need to be designed to minimize interference with OU4 investigation and possible remediation. - Would need to treat groundwater (including inorganics) to concentrations that comply with New Jersey Pollutant Discharge Elimination System (NJPDES) requirements for FW-2 streams.	Low to moderate depending on treatment needs	X	
		Discharge to POTW	- Treated water discharged to local POTW.	- Effective and reliable means of discharging water.	- Readily implementable. Treated water from the soil remedy for OU2 at the Cornell-Dubilier site is currently being discharged to a POTW. - Require a permit from the POTW. Need to verify that the POTW capacity limits will not be exceeded.	Low to moderate, depending on POTW fees.	X	
		Deep well injection	- Injection of treated water at the site via deep injection wells.	- Effectiveness is dependent on finding transmissive zones in the fractured rock to accept the fluid flow.	- May be difficult to inject high volumes of water into fractured bedrock, especially if degree of fracturing diminishes with depth. - Requires an underground injection permit from the NJDEP. Extensive assessment may be needed to obtain a permit.	Moderate capital cost; moderate O&M cost.		X

N/A – Not Applicable

TABLE 6-1
Cost Estimate for Alternative 1

Alternative 1 No Action		OPINION OF PROBABLE COST				
Site:	Cornell-Dubilier Electronics Superfund Site	Description: Alternative 1 involves nominal data collection to support preparation of CERCLA 5-year remedy reviews. It is assumed that annual sampling will be performed at five existing monitoring locations.				
Location:	South Plainfield, New Jersey					
Phase:	Feasibility Study (-30% to +50%)					
Base Year:	2011					
Date:	July 2011					
CAPITAL COSTS:						
DESCRIPTION		QTY	UNIT	UNIT COST	TOTAL	NOTES:
Sample Collection Work Plan		1	lump sum	\$30,000	\$30,000	
SUBTOTAL					\$30,000	
Design/Project Management (4)		10%			\$3,000	
SUBTOTAL					\$3,000	
TOTAL CAPITAL COST					\$33,000	
OPERATION, MAINTENANCE, AND MONITORING (OM&M) COSTS						
DESCRIPTION			UNIT	UNIT COST	TOTAL	NOTES:
Annual Costs, Years 1-30 (annual monitoring)						
Analytical Laboratory		1	lump sum	\$35,160	\$35,160	
Data Validation (10% of analytical cost)(1)		1	lump sum	\$3,520	\$3,520	
Field Equipment and Cooler Shipping (2)		1	per event	\$4,000	\$4,000	
Sample Collection Labor (3)		110	hour	\$110	\$12,100	
IDW Disposal		10	drum	\$500	\$5,000	
Annual Monitoring Well Maintenance		1	lump sum	\$1,000	\$1,000	
Reports		1	each	\$15,000	\$15,000	
SUBTOTAL					\$75,780	
Project Management (4)		10%			\$7,578	
Engineering and Technical Support (4)		10%			\$7,578	
SUBTOTAL					\$91,000	
Preparation of Five-Year Reviews						
Five-Year Review Preparation		1	lump sum	\$30,000	\$30,000	
SUBTOTAL					\$30,000	
Project Management (4)		10%			\$3,000	
SUBTOTAL					\$33,000	
PRESENT VALUE ANALYSIS:						
COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (2.3%)	PRESENT VALUE	NOTES:	
Capital Cost	\$33,000	\$33,000	1.00	\$33,000		
Annual Monitoring, Years 1-30	\$2,730,000	\$91,000	21.50	\$1,957,000		
5-Yr Reviews, Years 5, 10, 15, 20, 25, 30	\$198,000	\$33,000	4.11	\$136,000		
				\$2,126,000		
TOTAL PRESENT VALUE OF ALTERNATIVE				\$2,126,000		
TOTAL NON-DISCOUNTED WORTH OF ALTERNATIVE 1 \$2,961,000						

Footnotes

- 1 Includes VOCs, PCBs, and metals at all wells; pesticides, SVOCs, and dioxin/furans at selected wells and ports (see Attachment 1).
- 2 Includes tubing, pumps, decon equipment, flow-through water quality meters. Also includes overnight shipping of coolers.
- 3 Assume a crew of 3 people and a duration of 3 field days for sample collection. Assume that 1 person spends 2 days doing mob/demob.
- 4 In accordance with EPA Guide to Developing and Documenting Cost Estimates During the Feasibility Study (EPA 540-R-00-002)

TABLE 6-2

Cost Estimate for Alternative 2

Alternative 2

MNA with Institutional Controls

OPINION OF PROBABLE COST

Site: Cornell-Dubilier Electronics Superfund Site
Location: South Plainfield, New Jersey
Phase: Feasibility Study (-30% to +50%)
Base Year: 2011
Date: July 2011

Description: Alternative 2 consists of institutional controls and monitored natural attenuation (MNA) using the existing well network with 2 additional wells to be installed. Capital costs are incurred in Year 1. O&M costs are incurred in Years 2-30.

CAPITAL COSTS:

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES:
Monitoring Well Installation (1)	4	each	\$80,000	\$320,000	
FLUTE Liner Installation (2)	4	each	\$100,000	\$400,000	
Oversight for Driller, Geophysics, and Liner Installation (600	hour	\$110	\$66,000	
MNA Work Plan (4)	1	lump sum	\$50,000	\$50,000	
Institutional Controls (5)	1	lump sum	\$50,000	\$50,000	
SUBTOTAL				\$886,000	
Scope and Bid Contingency (9)	15%			\$132,900	
Design/Project Management (9)	8%			\$70,900	
SUBTOTAL				\$204,000	
TOTAL CAPITAL COST				\$1,090,000	

OPERATION, MAINTENANCE, AND MONITORING (OM&M) COSTS

DESCRIPTION	UNIT	UNIT COST	TOTAL	NOTES:
Annual Costs, Years 1-2 (quarterly monitoring)				
Analytical Laboratory (6)	1	lump sum	\$485,200	\$485,200
Data Validation (10% of analytical cost)	1	lump sum	\$48,520	\$48,520
Field Equipment and Cooler Shipping (7)	4	per event	\$20,000	\$80,000
Sample Collection Labor (four events) (8)	1,200	hour	\$110	\$132,000
IDW Disposal	60	drum	\$500	\$30,000
Annual Monitoring Well Maintenance	1	lump sum	\$5,000	\$5,000
Reports (10)	4	each	\$30,000	\$120,000
SUBTOTAL			\$900,720	
Project Management (9)	8%		\$72,058	
Engineering and Technical Support (9)	10%		\$90,072	
SUBTOTAL			\$1,063,000	
Annual Costs, Years 3-5 (semi-annual monitoring)				
Analytical Laboratory (6)	1	lump sum	\$304,100	\$304,100
Data Validation (10% of analytical cost)	1	lump sum	\$30,410	\$30,410
Field Equipment and Cooler Shipping (7)	2	per event	\$20,000	\$40,000
Sample Collection Labor (four events) (8)	600	hour	\$110	\$66,000
IDW Disposal	30	drum	\$500	\$15,000
Annual Monitoring Well Maintenance	1	lump sum	\$5,000	\$5,000
Reports	2	each	\$30,000	\$60,000
SUBTOTAL			\$520,510	
Project Management (9)	8%		\$41,641	
Engineering and Technical Support (9)	10%		\$52,051	
SUBTOTAL			\$615,000	

TABLE 6-3a

Cost Estimate for Alternative 3a

Alternative 3a

Source Area Hydraulic Control + MNA+ Inst.Controls; Discharge to POTW

OPINION OF PROBABLE COST

Site: Cornell-Dubilier Electronics Superfund Site
 Location: South Plainfield, New Jersey
 Phase: Feasibility Study (-30% to +50%)
 Base Year: 2011

Description: Alternative 3 consists of Alternative 2 (MNA + ICs) plus hydraulic control at the source area using two extraction wells. It is assumed that average flow will be 40 gallons per minute (gpm). On-site ex situ treatment is assumed, followed by treated water discharge to the POTW. Capital costs and start-up costs are incurred in Year 1. O&M costs are incurred in Years 2-30.

Date: July 2011

CAPITAL COSTS:

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES:
Site Work (1a)	1	lump sum	\$100,000	\$100,000	
Concrete Pad Installation (1b)	3500	\$/sq-ft	\$30	\$105,000	
Pre-Engineered Building Installation (2)	3500	\$/sq-ft	\$90	\$315,000	
Trenching from Extraction Wells to Plant (3)	500	linear feet	\$70	\$35,000	
Trenching from Plant to POTW Tap (4)	500	linear feet	\$35	\$17,500	
Sewer Connection Fee (5)	1	lump sum	\$720,000	\$720,000	
DNAPL Separator (6)	1	lump sum	\$20,000	\$20,000	
Multi-Media Filters (7)	1	lump sum	\$25,000	\$25,000	
UV Oxidation System (8)	1	lump sum	\$260,000	\$260,000	
Carbon Vessels (9)	1	lump sum	\$50,000	\$50,000	
Filter Press (10)	1	lump sum	\$20,000	\$20,000	
Process Water Tanks (11)	23,000	\$/gallon	\$5	\$115,000	
Chemical Tanks (12)	2,600	\$/gallon	\$10	\$26,000	
Process Pumps (13)	9	\$/pump	\$3,000	\$27,000	
Chemical Pumps (14)	6	\$/pump	\$3,000	\$18,000	
Interior Piping Installation (15)	1	lump sum	\$145,000	\$145,000	
Interior Electrical Installation (16)	1	lump sum	\$87,000	\$87,000	
Control Panel (17)	1	lump sum	\$75,000	\$75,000	
Permitting (18)	1	lump sum	\$25,000	\$25,000	
Installation of Two Extraction Wells (19)	2	each	\$16,000	\$32,000	
Groundwater Extraction Pumps (20)	2	each	\$1,800	\$3,600	
SUBTOTAL				\$2,221,100	
Design/Reporting (12%) (21) (22)	12%			\$266,600	
Onsite Construction Management and Oversight (8%)	8%			\$177,700	
Project Management and Technical Support (6%)	6%			\$133,300	
Scope (Design) Contingency (20%) (22)	20%			\$444,300	
Bid Contingency (20%) (22)	20%			\$444,300	
TOTAL CAPITAL COST				\$3,688,000	

START-UP COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES:
Senior Engineer Oversight (start-up)	100	\$/Hour	\$160	\$16,000	
Technician (start-up) - two technicians	320	\$/Hour	\$110	\$35,200	
Field Monitoring Equipment (start-up)	20	\$/Day	\$150	\$3,000	
Perdiem / Travel Expense (start-up)	25	\$/Day	\$150	\$3,750	
Misc Materials (start-up)	1	lump sum	\$2,500	\$2,500	
SUBTOTAL				\$60,450	
Reporting (25%)	25%			\$15,113	
Project Management and Technical Support (25%)	25%			\$15,113	
TOTAL START-UP COST				\$91,000	

TABLE 6-3a

Cost Estimate for Alternative 3a

Alternative 3a

Source Area Hydraulic Control + MNA+ Inst.Controls; Discharge to POTW

OPINION OF PROBABLE COST

- 26 95% H2SO4. Reduce influent pH from neutral to approx. 6.0 SU.
27 20% NAOH. Raise Effluent of GAC to approx. 6.5 SU
28 50% H2O2. Assume continuous operation at approx. 100ppm
29 Assume lamp life of 3000hrs each
30 Assume each 2000# vessel has 3 month life
31 Assume production of 2 drums per month
32 Assume production of 2 drums per month
33 Assume one full time operator required to man the plant
34 Assume monthly analytical samples collected from 4 sample locations
35 Discount rate is obtained from the Office of Management and Budget (OMB) Circular A-94, Guidelines and Discount Rates for Benefit Cost Analysis of Federal Programs, December 2010

List of Acronyms

LS - Lump Sum

LF - Linear Feet

DNAPL - Dense Non Aqueous Phase Liquids

sq-ft - square feet

OM - operation and maintenance

TABLE 6-3b
Cost Estimate for Alternative 3b

Alternative 3b

Source Area Hydraulic Control + MNA+ Inst.Controls; Discharge to Bound Brook

OPINION OF PROBABLE COST

Site: Cornell-Dubilier Electronics Superfund Site
Location: South Plainfield, New Jersey
Phase: Feasibility Study (-30% to +50%)
Base Year: 2011

Description: Alternative 3 consists of Alternative 2 (MNA + ICs) plus hydraulic control at the source area using two extraction wells. It is assumed that average flow will be 40 gallons per minute (gpm). On-site ex situ treatment is assumed, followed by treated water discharge to Bound Brook. Capital costs and start-up costs are incurred in Year 1. O&M costs are incurred in Years

Date: July 2011

CAPITAL COSTS:

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES:
Site Work (1a)	1	lump sum	\$100,000	\$100,000	
Concrete Pad Installation (1b)	3500	\$/sq-ft	\$30	\$105,000	
Pre-Engineered Building Installation (2)	3500	\$/sq-ft	\$90	\$315,000	
Trenching from Extraction Wells to Plant (3)	500	linear feet	\$70	\$35,000	
Trenching from Plant to Bound Brook Discharge (4)	500	linear feet	\$35	\$17,500	
DNAPL Separator (5)	1	lump sum	\$20,000	\$20,000	
Multi-Media Filters (6)	1	lump sum	\$25,000	\$25,000	
Catalytic Media Filters (7)	1	lump sum	\$7,500	\$7,500	
UV Oxidation System (8)	1	lump sum	\$260,000	\$260,000	
Carbon Vessels (9)	1	lump sum	\$50,000	\$50,000	
Filter Press (10)	1	lump sum	\$20,000	\$20,000	
Process Water Tanks (11)	23,000	\$/gallon	\$5	\$115,000	
Chemical Tanks (12)	2,600	\$/gallon	\$10	\$26,000	
Process Pumps (13)	9	\$/pump	\$3,000	\$27,000	
Chemical Pumps (14)	6	\$/pump	\$3,000	\$18,000	
Interior Piping Installation (15)	1	lump sum	\$145,000	\$145,000	
Interior Electrical Installation (16)	1	lump sum	\$87,000	\$87,000	
Control Panel (17)	1	lump sum	\$75,000	\$75,000	
Permitting (18)	1	lump sum	\$100,000	\$100,000	
Installation of Two Extraction Wells (19)	2	each	\$16,000	\$32,000	
Groundwater Extraction Pumps (20)	2	each	\$1,800	\$3,600	
SUBTOTAL				\$1,583,600	
Design/Reporting (12%) (21) (22)	12%			\$190,100	
Onsite Construction Management and Oversight (8%)	8%			\$126,700	
Project Management and Technical Support (6%)	6%			\$95,100	
Scope (Design) Contingency (20%) (22)	20%			\$316,800	
Bid Contingency (20%) (22)	20%			\$316,800	
TOTAL CAPITAL COST				\$2,630,000	

START-UP COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES:
Senior Engineer Oversight (start-up)	100	\$/Hour	\$160	\$16,000	
Technician (start-up) - two technicians	320	\$/Hour	\$110	\$35,200	
Field Monitoring Equipment (start-up)	20	\$/Day	\$150	\$3,000	
Perdiem / Travel Expense (start-up)	25	\$/Day	\$150	\$3,750	
Misc Materials (start-up)	1	lump sum	\$2,500	\$2,500	
SUBTOTAL				\$60,450	
Reporting (25%)	25%			\$15,113	
Project Management and Technical Support (25%)	25%			\$15,113	
TOTAL START-UP COST				\$91,000	

TABLE 6-3b

Cost Estimate for Alternative 3b

Alternative 3b

Source Area Hydraulic Control + MNA+ Inst.Controls; Discharge to Bound Brook

OPINION OF PROBABLE COST

- 23 Electrical consumption based on 60kW UV system plus 15kW for pumps and 10kW for other misc. uses.
24 95% H2SO4. Reduce influent pH from neutral to approx. 6.0 SU
25 20% NaOH. Raise Effluent of GAC to approx. 6.5 SU
26 50% H2O2. Assume continuous operation at approx. 125ppm (100ppm + 25ppm residual for catalytic filter)
27 Assume lamp life of 3000hrs each
28 Assume each 2000# vessel has 3 month life
29 Assumed annual media changeout in all three vessels (1500# x 3) + Disposal
30 Assume production of 2 drums per month
31 Assume production of 2 drums per month
32 Assume one full time operator required to man the plant
33 Assume monthly analytical samples collected from 4 sample locations
34 Discount rate is obtained from the Office of Management and Budget (OMB) Circular A-94, Guidelines and Discount Rates for Benefit
Cost Analysis of Federal Programs, December 2010

List of Acronyms

LS - Lump Sum

LF - Linear Feet

DNAPL - Dense Non Aqueous Phase Liquids

sq-ft - square feet

OM - operation and maintenance

TABLE 6-4

Cost Estimate for Alternative 4

Alternative 4

Thermal Source Area Treatment plus MNA + Inst. Controls

OPINION OF PROBABLE COST

Site: Cornell-Dubilier Electronics Superfund Site
Location: South Plainfield, New Jersey
Phase: Feasibility Study (-30% to +50%)
Base Year: 2011
Date: July 2011

Description: Alternative 4 consists of Alternative 2 (MNA + ICs) plus thermal treatment in the vicinity of MW-14 using TCH and SEE. On-site treatment would be performed for water and vapors removed by the SVE and MPE wells, followed by treated water discharge to the POTW. All thermal treatment costs are incurred in Year 1. Costs are based on estimate provided by TerraTherm on March 23, 2011.

CAPITAL COSTS¹:

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES:
Site Activities Pre Thermal Operation					
Mobilization	1	lump sum	\$246,000	\$246,000	
Drilling and Well Installation	1	lump sum	\$3,168,000	\$3,168,000	
Vapor cover installation	1	lump sum	\$422,000.0	\$422,000	
Well-field piping	1	lump sum	\$853,000	\$853,000	
TCH power equipment installation	1	lump sum	\$156,000	\$156,000	
Steam generation system installation	1	lump sum	\$81,000	\$81,000	
Treatment system installation	1	lump sum	\$925,000	\$925,000	
Electrical installation, well-field and process	1	lump sum	\$114,000	\$114,000	
Instrument and monitoring system installation	1	lump sum	\$59,000	\$59,000	
Pre-startup and shakedown	1	lump sum	\$64,000	\$64,000	
Thermal Treatment Operations					
TCH power equipment rental	1	lump sum	\$78,000	\$78,000	
Steam generation system rental	1	lump sum	\$122,000	\$122,000	
Effluent treatment system rental	1	lump sum	\$83,000	\$83,000	
Labor, travel, per diem	1	lump sum	\$240,000	\$240,000	
Process monitoring, sampling, and analysis	1	lump sum	\$57,000	\$57,000	
Waste and GAC	1	lump sum	\$1,000	\$1,000	
Repair/maintenance	1	lump sum	\$52,000	\$52,000	
Tools, rentals, and fees	1	lump sum	\$19,000	\$19,000	
Utilities					
Power	1	lump sum	\$1,658,000	\$1,658,000	
Gas	1	lump sum	\$248,000	\$248,000	
Caustic	1	lump sum	\$2,000	\$2,000	
Demobilization					
Well decommissioning	1	lump sum	\$201,000	\$201,000	
Site Cleanance and Demob	1	lump sum	\$118,000	\$118,000	
Reporting	1	lump sum	\$47,000	\$47,000	
Thermal Vendor Indirect Costs					
Field Support	1	lump sum	\$68,000	\$68,000	
Home office support	1	lump sum	\$114,000	\$114,000	
TCH licensing fees	1	lump sum	\$246,000	\$246,000	
SUBTOTAL				\$9,442,000	
Project Management and Design (13%) (2)	13%	lump sum		\$1,227,500	
Onsite Construction Management and Oversight (6%)	6%			\$566,600	
Scope (Design) Contingency (15%) (2)	15%			\$1,416,300	
Bid Contingency (15%) (2)	15%			\$1,416,300	
TOTAL CAPITAL COST				\$14,069,000	

TABLE 6-5

Cost Estimate for Alternative 5

Alternative 5

In Situ Chemical Oxidation at Source Area + MNA + Inst. Controls

OPINION OF PROBABLE COST

Site: Cornell-Dubilier Electronics Superfund Site
 Location: South Plainfield, New Jersey
 Phase: Feasibility Study (-30% to +50%)
 Base Year: 2011

Description: Alternative 5 consists of Alternative 2 (MNA + ICs) plus ISCO using activated persulfate in the vicinity of MW-14. Pilot testing will be performed to refine the injection radius of influence. It is assumed that quarterly injections will be performed for a period of 5 years. MNA monitoring would start in year 1 and continue through year 30.

Date: July 2011

CAPITAL COSTS:

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES:
Pilot Testing					
Pilot test work plan and permitting	1	LS	\$50,000	\$50,000	
Install injection and monitoring wells	4	EA	\$8,000	\$32,000	
Field activities for pilot testing	1	LS	\$100,000	\$100,000	
Pilot test reporting	1	LS	\$75,000	\$75,000	
SUBTOTAL				\$257,000	
Full-Scale ISCO Planning and Well Installation					
Remedial Design and Permitting	1	LS	\$80,000	\$80,000	
Mobilization	1	LS	\$100,000	\$100,000	
Shallow (4-inch ID, 45 ft bgs, 20 foot open borehole)	35	EA	\$8,000	\$280,000	
Intermediate (4-inch ID, 65 ft bgs, 20 ft open borehole)	35	EA	\$11,000	\$385,000	
Field oversight (incl. per diem)	120	Day	\$1,500	\$180,000	
SUBTOTAL				\$1,025,000	
SUBTOTAL				\$1,282,000	
Design and Project Management*	18%			\$230,760	
Construction Management*	8%			\$102,560	
Scope Contingency*	10%			\$128,200	
Bid Contingency*	10%			\$128,200	
TOTAL CAPITAL COST				\$1,872,000	

OPERATION, MAINTENANCE, AND MONITORING (OM&M) COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES:
ISCO Injections and Monitoring (Assuming quarterly injections)					
Persulfate (for 4 injections)	11,339	lbs	\$1.45	\$16,442	
25 wt% NaOH (for 4 injections)	1,724	gallons	\$4.58	\$7,896	
Injection Contractor	60	day	\$3,000	\$180,000	
Analytical Laboratory	1	lump sum	\$30,900	\$30,900	
Data Validation (10% of analytical cost)	1	lump sum	\$3,090	\$3,090	
Field Equipment and Cooler Shipping	4	per event	\$1,500	\$6,000	
Sample Collection Labor (four events)	400	hour	\$110	\$44,000	
IDW Disposal	12	drum	\$500	\$6,000	
Data Evaluation and Reports	4	ea	\$25,000	\$100,000	
SUBTOTAL				\$394,328	
Project Management*	8%			\$102,560	
Scope Contingency*	10%			\$128,200	
Bid Contingency*	10%			\$128,200	
TOTAL ANNUAL O&M COST				\$754,000	

PRESENT VALUE ANALYSIS:

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (2.3%)	PRESENT VALUE	NOTES:
Capital	1	\$1,872,000	\$1,872,000	1.00	\$1,872,000	
Annual OM&M	2-6	\$3,770,000	\$754,000	4.57	\$3,265,000	
					\$5,137,000	
TOTAL PRESENT VALUE OF ISCO AT SOURCE AREA					\$5,137,000	
TOTAL PRESENT WORTH FOR 30 YEARS OF MNA (see separate sheet)					\$9,170,000	
TOTAL PRESENT WORTH OF ALTERNATIVE 5					\$14,307,000	
TOTAL NON-DISCOUNTED WORTH OF ALTERNATIVE 5 (Including MNA)		\$16,863,000				

* Per USEPA 540-R-00-002, "A Guide to Developing and Documenting Cost Estimates During the Feasibility Study". July 2000.

TABLE 6-6
Cost Estimate for Alternative 6

Alternative 6
Source Area In Situ Biological Treatment + MNA + Inst. Controls

OPINION OF PROBABLE COST

Site: Cornell-Dubilier Electronics Superfund Site
Location: South Plainfield, New Jersey
Phase: Feasibility Study (-30% to +50%)
Base Year: 2011

Description: Alternative 6 consists of Alternative 2 (MNA + LTM) plus in-situ biological treatment of chlorinated VOCs in the source area (defined as the area surrounding MW-14S/D). It is assumed that one pore volume (secondary porosity) is approximately 3,500 gallons and that 10 amendment injections of 3500 gallons will be required, along with the additional of micro-organisms. Capital costs are incurred in Years 1 (pilot study) and 2. O&M costs are incurred in years 2 to 11.

Date: July 2011

CAPITAL COSTS:

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES:
Pilot Testing					
Pilot test work plan and permitting	1	LS	\$50,000	\$50,000	
Install injection and monitoring wells	4	EA	\$8,000	\$32,000	
Field activities for pilot testing	1	LS	\$80,000	\$80,000	
Pilot test reporting	1	LS	\$60,000	\$60,000	
SUBTOTAL				<u>\$222,000</u>	
Full Scale Injection Well Installation					
Mobilization	1	LS	\$100,000	\$100,000	
Shallow (4-inch ID, 45 ft bgs, 20 foot open borehole)	45	ea	\$8,000	\$360,000	
Intermediate (4-inch ID, 65 ft bgs, 20 ft open borehole)	45	ea	\$11,000	\$495,000	
Field Oversight (incl. per diem)	120	day	\$1,500	\$180,000	
SUBTOTAL				<u>\$1,135,000</u>	
SUBTOTAL				<u>\$1,357,000</u>	
Design and Project Management	18%			\$245,000	
Construction Management*	8%			\$109,000	
Scope (Design) Contingency	10%			\$136,000	
Bid Contingency	10%			\$136,000	
TOTAL CAPITAL COST				\$1,983,000	

OPERATION, MAINTENANCE, AND MONITORING (OM&M) COSTS (Years 2 to 11)

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES:
Amendment Injections and Monitoring (Assumes annual injections and semi-annual monitoring)					
Mobilization	1	LS	\$10,000	\$10,000	
Injection Contractor	15	day	\$3,000	\$45,000	
Amendment (10% mixture Emulsified Veg. Oil)	350	gal	\$12.27	\$4,295	
Micro-organism Inoculation (KB-1 *)	1	LS	\$15,000	\$15,000	
Oversight	15	day	\$720	\$10,800	
Analytical Laboratory	1	lump sum	\$15,450	\$15,450	
Data Validation (10% of analytical cost)	1	lump sum	\$1,550	\$1,550	
Field Equipment and Cooler Shipping	2	per event	\$1,500	\$3,000	
Sample Collection Labor (two events)	200	hour	\$110	\$22,000	
IDW Disposal	6	drum	\$500	\$3,000	
Data Evaluation and Reports	2	ea	\$25,000	\$50,000	
SUBTOTAL				<u>\$95,000</u>	
Project Management*	8%			\$10,880	
Scope Contingency*	10%			\$13,600	
Bid Contingency*	10%			\$13,600	
TOTAL ANNUAL O&M COST				\$134,000	

TABLE 6-7

Remedial Alternatives Cost Summary

OPINION OF PROBABLE COST SUMMARY

Site: Cornell-Dubilier Electronics Superfund Site
Location: South Plainfield, New Jersey
Phase: Feasibility Study (-30% to +50%)
Base Year: 2011
Date: July 2011

Alternative	Description	Capital Costs (incl. startup)	Estimated Remediation Time (years)	Present Value of O&M Costs	Present Value of MNA+ ICs for Alts 3,4,5,&6	Total Present Value
Alternative 1	NO ACTION	\$33,000	30	\$2,093,000	—	\$2,126,000
Alternative 2	MNA + INSTITUTIONAL CONTROLS	\$1,090,000	30	\$8,080,000	—	\$9,170,000
Alternative 3a	SOURCE AREA HYDRAULIC CONTROL + MNA + INSTITUTIONAL CONTROLS - DISCHARGE TO POTW	\$3,779,000	30	\$26,015,000	\$9,170,000	\$38,964,000
Alternative 3b	SOURCE AREA HYDRAULIC CONTROL + MNA + INSTITUTIONAL CONTROLS - DISCHARGE TO BOUND BROOK	\$2,721,000	30	\$17,394,000	\$9,170,000	\$29,285,000
Alternative 4	SOURCE AREA THERMAL TREATMENT + MNA + INSTITUTIONAL CONTROLS	\$14,069,000	30	—	\$9,170,000	\$23,239,000
Alternative 5	SOURCE AREA ISCO TREATMENT + MNA + INSTITUTIONAL CONTROLS	\$1,872,000	30	\$3,265,000	\$9,170,000	\$14,307,000
Alternative 6	SOURCE AREA BIOLOGICAL TREATMENT + MNA + INSTITUTIONAL CONTROLS	\$1,983,000	30	\$1,158,000	\$9,170,000	\$12,311,000

Cost Estimate - Attachment 1
Summary of No Action Alternative Monitoring Program
Cornell-Dubiller Electronics Superfund Site
South Plainfield, New Jersey

Years 1 to 30 (annual monitoring)									
Well ID	Single Screen or Water FLUTE port #	Depth Interval (ft bgs)		Trace Volatiles	Semi-Volatiles	Pesticides	PCB Aroclors	TAL Metals (ICP-MS)	Dioxins/Furans
Cost per Analysis ²				\$102.29	\$181.14	\$119.00	\$97.57	\$128.89	\$800.00
Deep Bedrock Multi-Port Monitoring Wells									
ERT-1	1	24	29	1	1	1	1	1	1
	2	33	43	1	1	1	1	1	1
	3	46	56	1	1	1	1	1	
	4	59	64	1	1	1	1	1	1
	5	67	77	1	1	1	1	1	1
	6	100	105	1	1	1	1	1	
	7	112	117	1	1	1	1	1	1
	8	135	140	1	1	1	1	1	1
MW-14S	1	30	35	1	1	1	1	1	1
	2	41	46	1	1	1	1	1	
	3	55	60	1	1	1	1	1	1
	4	65	70	1	1	1	1	1	1
MW-14D	1	80	85	1	1	1	1	1	1
	2	123	133	1	1	1	1	1	
	3	199	209	1	1	1	1	1	1
MW-16	1	20	30	1	1	1	1	1	
	2	40	50	1	1	1	1	1	
	3	85	95	1	1	1	1	1	
	4	108	118	1	1	1	1	1	
	5	135	145	1	1	1	1	1	
	6	170	180	1	1	1	1	1	
	7	195	205	1	1	1	1	1	1
MW-20	1	25	35	1			1	1	
	2	85	95	1			1	1	
	3	125	135	1			1	1	
	4	175	185	1			1	1	
	5	205	215	1			1	1	
	6	250	260	1			1	1	
	7	297	307	1			1	1	
	8	355	365	1			1	1	
MW-23	1	60	70	1			1	1	
	2	120	130	1			1	1	
	3	170	180	1			1	1	
	4	226	236	1			1	1	
	5	258	268	1			1	1	
	6	316	326	1			1	1	
	7	350	360	1			1	1	
	8	406	416	1			1	1	
	9	444	454	1			1	1	
SUBTOTAL				39	22	22	39	39	12
FIELD QC SAMPLES									
Duplicate	10% for all analyses			4	2.2	2.2	3.9	3.9	1.2
MS/MSD	5% for all analyses (counts as			4	2.2	2.2	3.9	3.9	1.2
Trip Blank	1 for every 15 VOC samples			3					
TOTAL NO. OF SAMPLES				50	26.4	26.4	46.8	46.8	14.4
TOTAL COSTS				\$5,115	\$4,782	\$3,142	\$4,566	\$6,032	\$11,520

Notes:

- 1 MNA Parameters includes iron (dissolved), chloride, nitrate, sulfate, manganese, alkalinity, and dissolved organic carbon
 - 2 Costs of analyses for trace volatiles, semi-volatiles, pesticides, PCB aroclors, and TAL metals are obtained from CLP prices posted by USEPA. The mean analytical laboratory price for 21-day turn around is used. Costs for the other analyses are obtained from laboratory quotes.
- Shaded Well IDs indicate that well is located on the former CDE facility.

Cost Estimate - Attachment 2
Summary of Monitored Natural Attenuation Program
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Well ID	Single Screen or Water FLUTE port #	Depth Interval (ft bgs)	Years 1 and 2 (per year)										Years 3 to 5 (per year)										Years 6 to 15 (per year)										Years 16 to 30 (per year)									
			Trace Volatiles	Semi-Volatiles	Pesticides	PCB Aroclors	TAL Metals (ICP-MS)	Dioxins/Furans	PCB Congeners	MNA Parameters [†]	Methane/ethane/ethene	Dehalococoides	Trace Volatiles	Semi-Volatiles	Pesticides	PCB Aroclors	TAL Metals (ICP-MS)	Dioxins/Furans	PCB Congeners	MNA Parameters [†]	Methane/ethane/ethene	Dehalococoides	Trace Volatiles	Semi-Volatiles	Pesticides	PCB Aroclors	TAL Metals (ICP-MS)	Dioxins/Furans	PCB Congeners	MNA Parameters [†]	Methane/ethane/ethene	Dehalococoides	Trace Volatiles	Semi-Volatiles	Pesticides	PCB Aroclors	TAL Metals (ICP-MS)	Dioxins/Furans	PCB Congeners	MNA Parameters [†]	Methane/ethane/ethene	Dehalococoides
Cost per Analysis ²			\$102.29	\$181.14	\$119.00	\$97.57	\$128.89	\$800.00	\$900.00	\$121.00	\$150.00	\$275.00	\$102.29	\$181.14	\$119.00	\$97.57	\$128.89	\$800.00	\$900.00	\$169.00	\$150.00	\$275.00	\$102.29	\$181.14	\$119.00	\$97.57	\$128.89	\$800.00	\$900.00	\$169.00	\$150.00	\$275.00	\$102.29	\$181.14	\$119.00	\$97.57	\$128.89	\$800.00	\$900.00	\$169.00	\$150.00	\$275.00
Shallow Bedrock Monitoring Wells																																										
MW-01A	1	24 49	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
MW-02A	1	24 49	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
MW-03	1	17 32	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
MW-04	1	29 49	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
MW-05	1	25 45.5	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
MW-06	1	29 44	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
MW-07	1	43 58	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
MW-08	1	42 57.5	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
MW-09	1	29 54	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
MW-10	1	37 52	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
MW-11	1	34 59	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
MW-12	1	35 60	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
Deep Bedrock Multi-Port Monitoring Wells																																										
ERT-1	1	24 29	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	2	33 43	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	3	46 56	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	4	59 64	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	5	67 77	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	6	100 105	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	7	112 117	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	8	135 140	4	2	2	2	2	2	2	4	4	1	2	2	2	2	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
ERT-2	1	25 35	4	2	2	2	2	2	2	4	4	1	2	2	2	1	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	2	40 50	4	2	2	2	2	2	2	4	4	1	2	2	2	1	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	3	54 59	4	2	2	2	2	2	2	4	4	1	2	2	2	1	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	4	70 75	4	2	2	2	2	2	2	4	4	1	2	2	2	1	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	5	97 107	4	2	2	2	2	2	2	4	4	1	2	2	2	1	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	6	113 123	4	2	2	2	2	2	2	4	4	1	2	2	2	1	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	7	127 137	4	2	2	2	2	2	2	4	4	1	2	2	2	1	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
ERT-3	1	27 37	4				1	1		4	4		2			1	1			2	2	2	1			1	1			1	1	0.5			0.5	0.5			0.5	0.5		
	2	55 65	4				1	1		4	4		2			1	1			2	2	2	1			1	1			1	1	0.5			0.5	0.5			0.5	0.5		
	3	90 105	4				1	1		4	4		2			1	1			2	2	2	1			1	1			1	1	0.5			0.5	0.5			0.5	0.5		
	4	110 120	4				1	1		4	4		2			1	1	</																								

TABLE 6-8
COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

	Alternative 1 No Action	Alternative 2 MNA with ICs	Alternative 3 Source Area Hydraulic Control with MNA and ICs	Alternative 4 Source Area Thermal Treatment with MNA and ICs	Alternative 5 Source Area In Situ Chemical Oxidation with MNA and ICs	Alternative 6 Source Area In Situ Bio- remediation with MNA and ICs
Threshold Criteria¹						
Overall protection of human health and the environment	NO – No actions would be performed, and only cursory monitoring would be performed to enable preparation of CERCLA five-year reviews. There would be no administrative system to control exposure to contaminated groundwater or to monitor the TI zone. Therefore, RAOs would not be met.	YES – Potential human exposure to groundwater would be controlled by the establishment and monitoring of a CEA and a TI zone. A rigorous monitoring program would be put in place to verify that contaminants are not migrating beyond the CEA and TI zones at concentrations that could pose a risk to receptors.	YES – Potential human exposure to groundwater would be controlled by the establishment and monitoring of a CEA and a TI zone. A rigorous monitoring program would be put in place to verify that contaminants are not migrating beyond the CEA and TI zones at concentrations that could pose a risk to receptors.	YES – Potential human exposure to groundwater would be controlled by the establishment and monitoring of a CEA and a TI zone. A rigorous monitoring program would be put in place to verify that contaminants are not migrating beyond the CEA and TI zones at concentrations that could pose a risk to receptors.	YES – Potential human exposure to groundwater would be controlled by the establishment and monitoring of a CEA and a TI zone. A rigorous monitoring program would be put in place to verify that contaminants are not migrating beyond the CEA and TI zones at concentrations that could pose a risk to receptors.	YES – Potential human exposure to groundwater would be controlled by the establishment and monitoring of a CEA and a TI zone. A rigorous monitoring program would be put in place to verify that contaminants are not migrating beyond the CEA and TI zones at concentrations that could pose a risk to receptors.
Compliance with ARARs	YES - A TI zone has been established for CDE OU3, and ARARs have been waived within the boundaries of the TI zone.	YES - A TI zone has been established for CDE OU3, and ARARs have been waived within the boundaries of the TI zone.	YES - A TI zone has been established for CDE OU3, and ARARs have been waived within the boundaries of the TI zone.	YES - A TI zone has been established for CDE OU3, and ARARs have been waived within the boundaries of the TI zone.	YES - A TI zone has been established for CDE OU3, and ARARs have been waived within the boundaries of the TI zone.	YES - A TI zone has been established for CDE OU3, and ARARs have been waived within the boundaries of the TI zone.
Balancing Criteria						
Long-term effectiveness and permanence	The effectiveness of natural attenuation processes would be unknown without an adequate monitoring network, and there would be no means to monitor the TI zone.	Alternative 2 includes a robust monitoring system to document groundwater quality and to monitor the TI zone. FRACTRAN model results indicate that chlorinated ethenes will persist at concentrations exceeding ARARs for very long time periods. However, the expectation is that the rate of plume front migration is very slow due to attenuation via matrix diffusion.	Hydraulic control in the source area would provide minor groundwater quality improvements; however, the time to achieve these benefits is long and chlorinated ethene concentrations still remain elevated for long time periods.	Thermal treatment in the source area would provide minor groundwater quality improvements; however, the time to achieve these benefits is long and chlorinated ethene concentrations still remain elevated for long time periods.	In situ chemical oxidation treatment in the source area would provide minor groundwater quality improvements; however, the time to achieve these benefits is long and chlorinated ethene concentrations still remain elevated for long time periods.	In situ biological treatment in the source area would provide minor groundwater quality improvements; however, the time to achieve these benefits is long and chlorinated ethene concentrations still remain elevated for long time periods.



SOURCE: U.S.G.S. TOPOGRAPHIC MAP,
7.5 MINUTE SERIES, PLAINFIELD, NEW JERSEY
QUADRANGLE, 1955, PHOTOREVISED 1981



Cornell-Dubilier Electronics
Superfund Site
South Plainfield, New Jersey

FORMER CDE FACILITY
LOCATION MAP

FIGURE 1-1



LEGEND

- Property Boundary
- Bound Brook

0 250 500 1,000 Feet

Source: New Jersey Geographic Information Network (NJ 2007 Ortho Imagery)

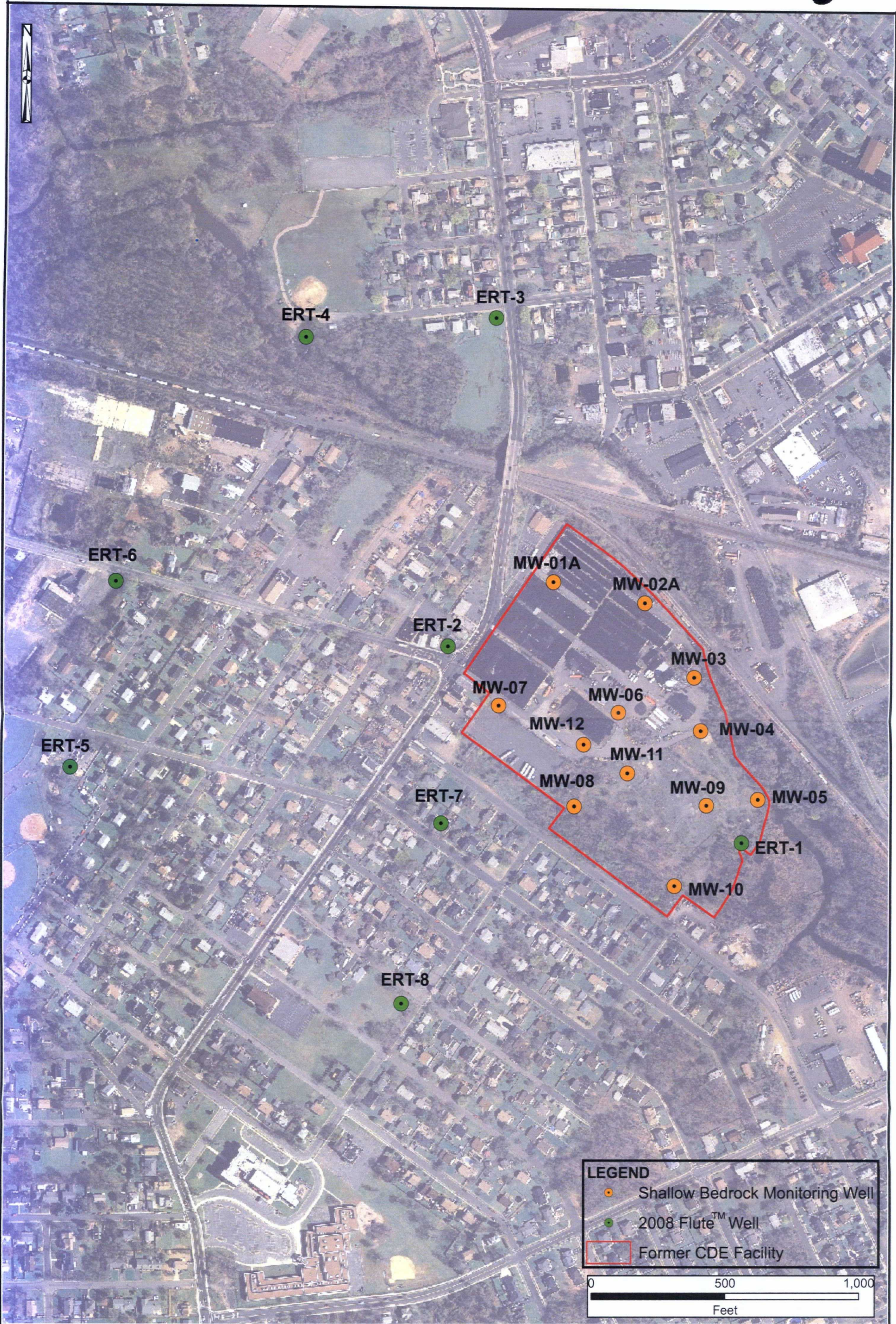
MALCOLM
PIRNIE

Cornell-Dubilier Electronics
Superfund Site

South Plainfield, NJ

2007 AERIAL PHOTOGRAPH

FIGURE 1-2



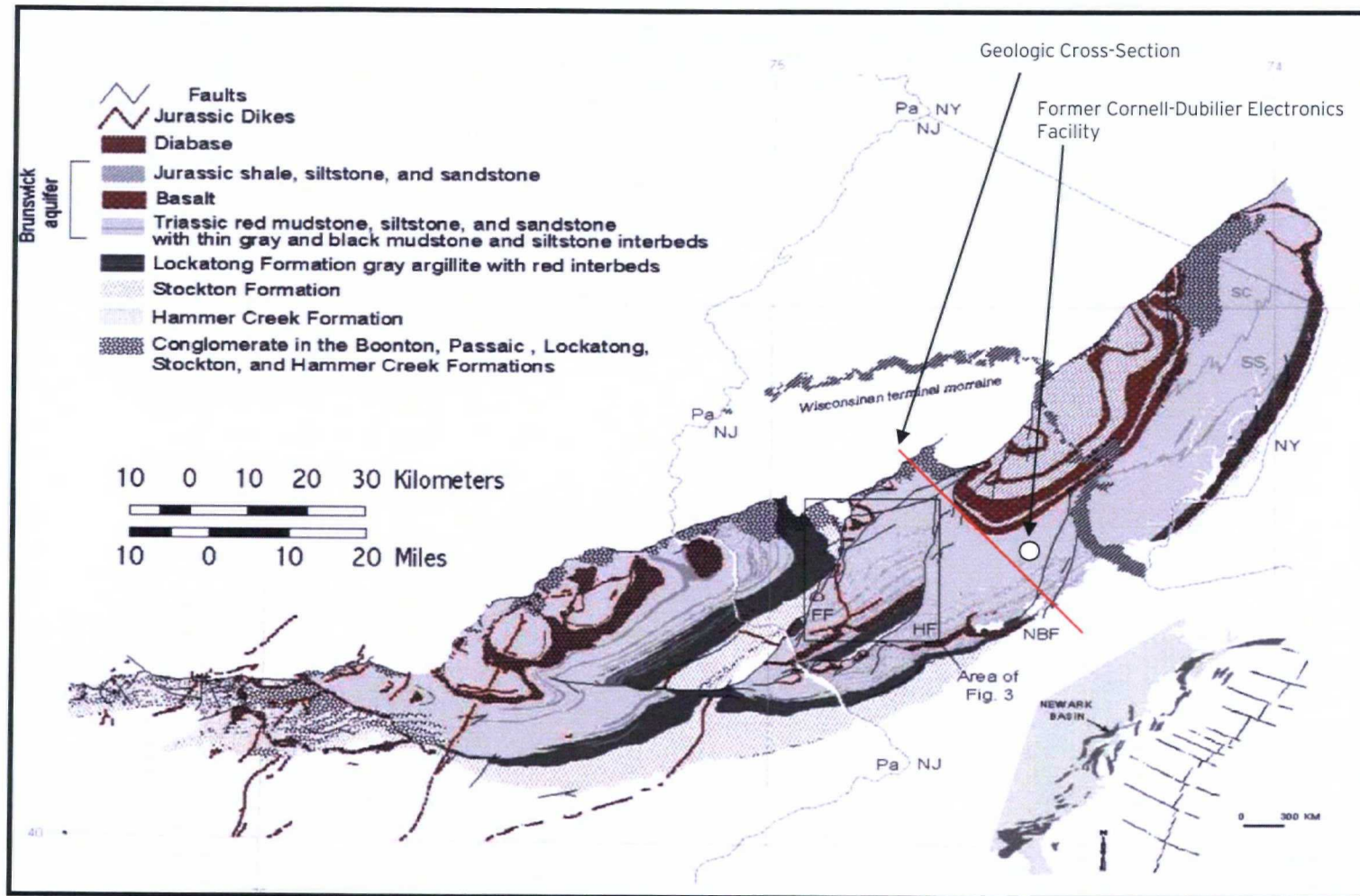
**MALCOLM
PIRNIE**



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Superfund Site
South Plainfield, New Jersey

Groundwater Monitoring Wells
from 2008 and Prior
Investigations

FIGURE 1-3



Source: Herman, 2001

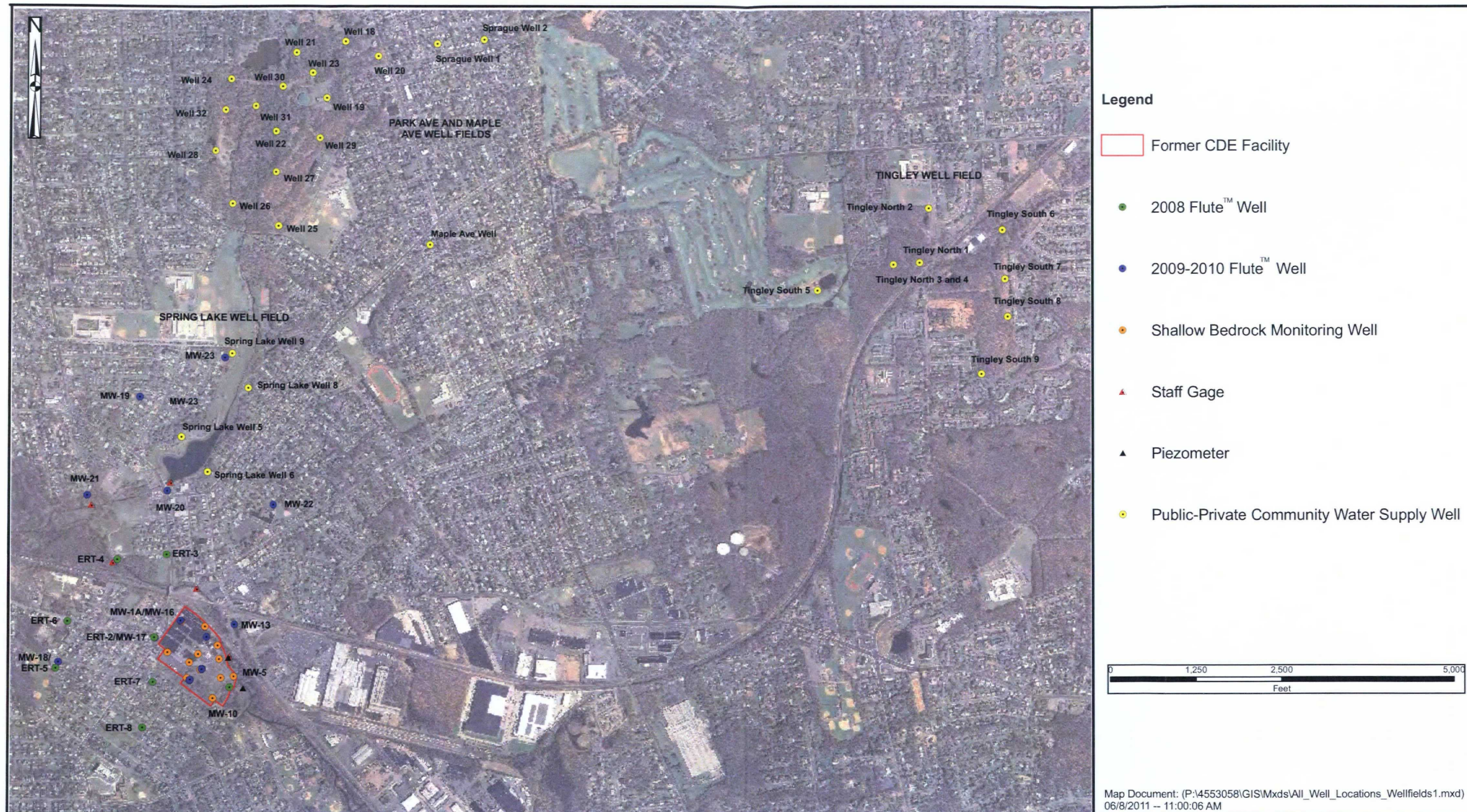
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Cornell-Dubilier Electronics
Superfund Site
South Plainfield, New Jersey

Generalized Geologic Map
of the Newark Basin

FIGURE 1-4



**MALCOLM
PIRNIE**



Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Surrounding Wellfield Locations

FIGURE 1-6



**MALCOLM
PIRNIE**

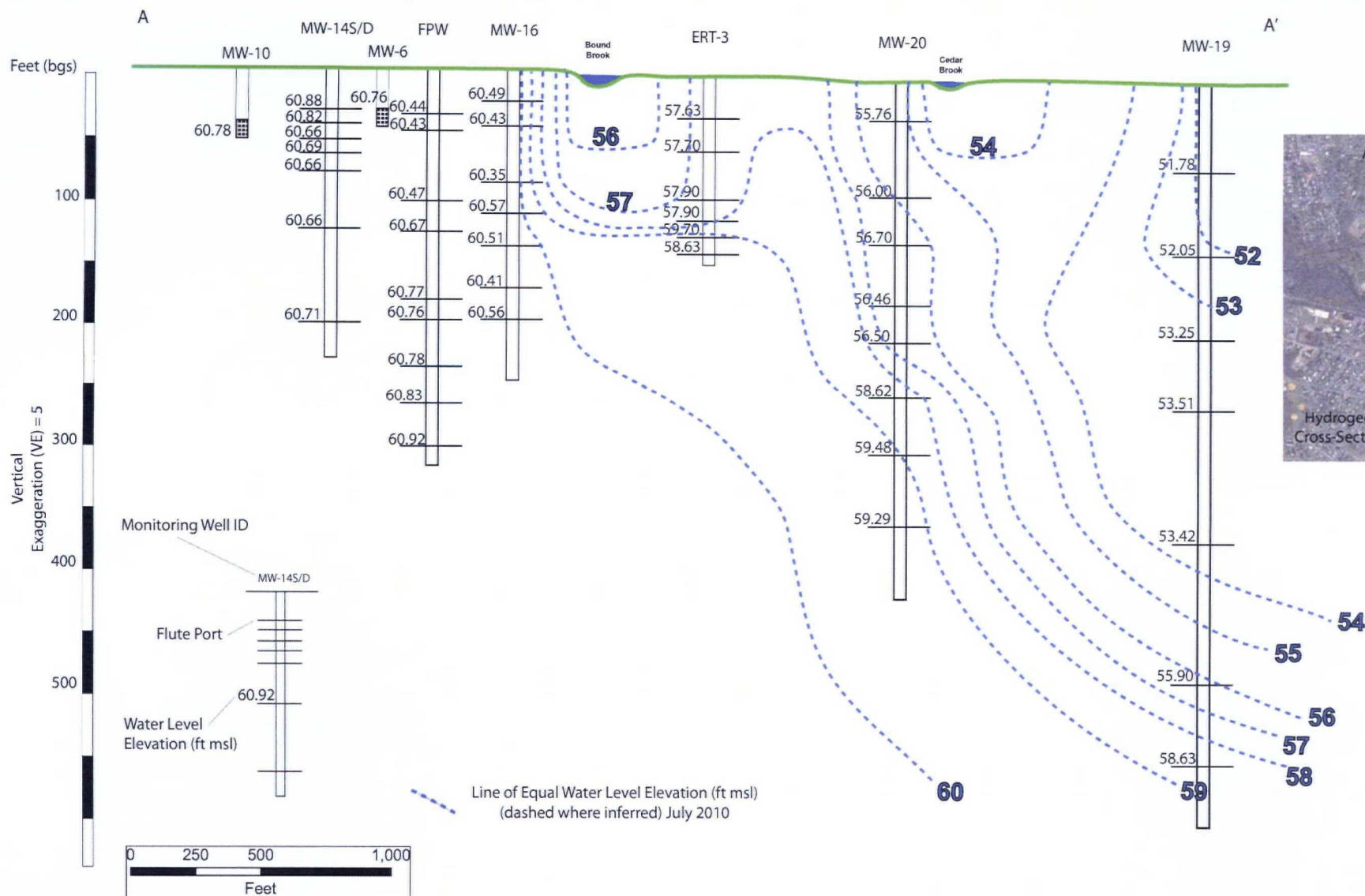


**Cornell-Dubilier Electronics
Superfund Site - OU3**
South Plainfield, New Jersey

**Potentiometric Surface of Shallow
Water Bearing Zone**
July 9, 2010

FIGURE 1-7





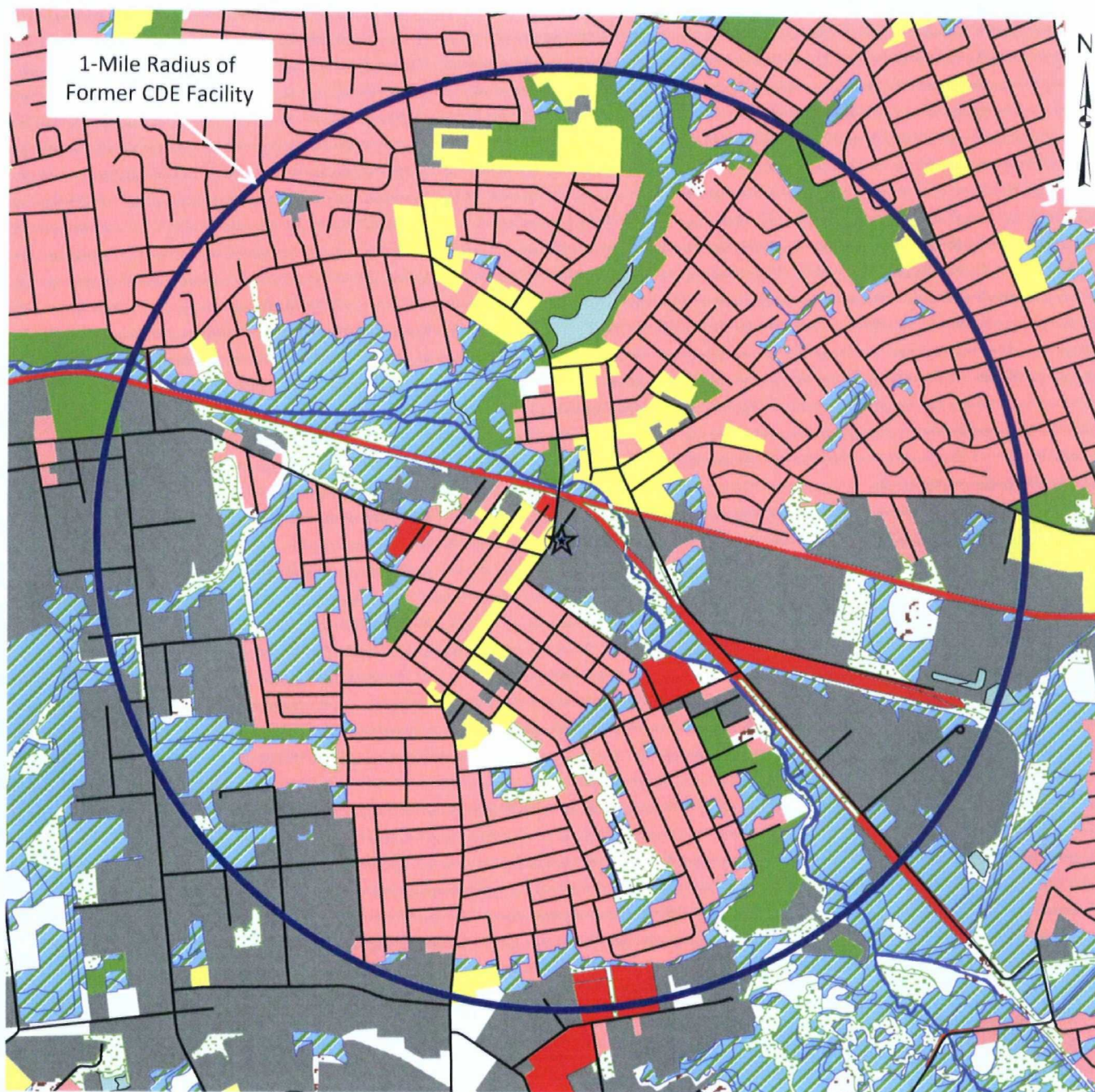
-  Piezometer
-  10/2009 Measurements
-  3/2010 Measurements
-  7/2010 Measurements



Cornell-Dubilier Electronics
Superfund Site
South Plainfield, New Jersey

Vertical Head Measurements 2009-2010 Events

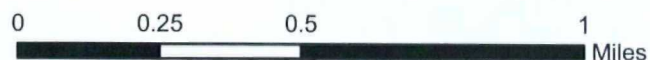
FIGURE 1-11



LEGEND

NJDEP 2002 Land Use/Land Cover	Commercial/Services	Transportation/Communication	Former CDE Facility
Wetlands	Scrub/Shrub	Residential	
Natural/Artificial Lakes	Forested	Streams	
Field/Cemetery	Urban/Industrial		

Source: NJDEP Bureau of Geographic Information Systems
(Updated as of March 10, 2008)



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PIRNIE**

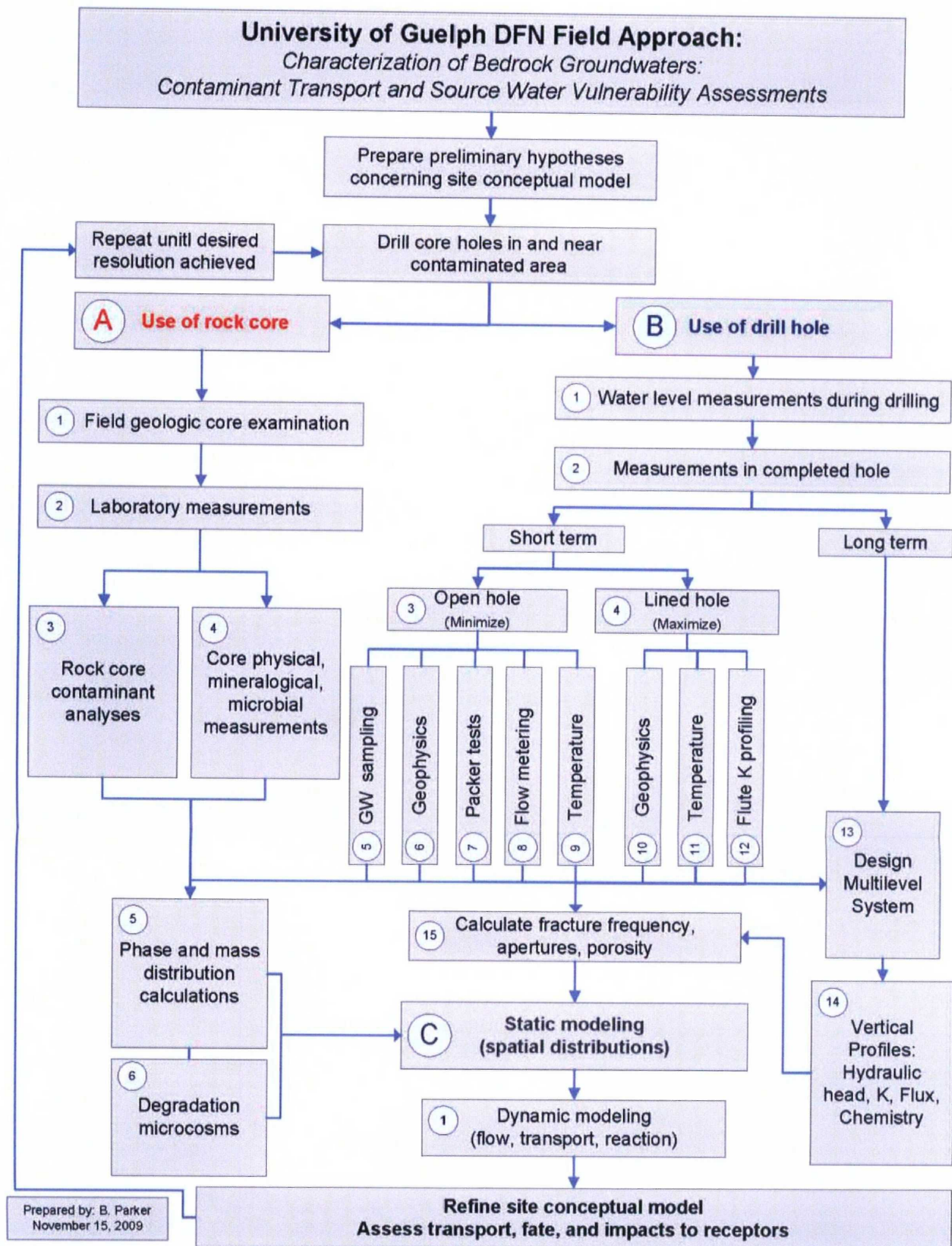


Cornell-Dubilier Electronics
Superfund Site

South Plainfield, NJ

LAND USE / LAND
COVER TYPES

FIGURE 1-12



The Discrete Fracture Network Approach (DFN) idealized investigation flow chart used to for the characteroization of fractured bedrock environments

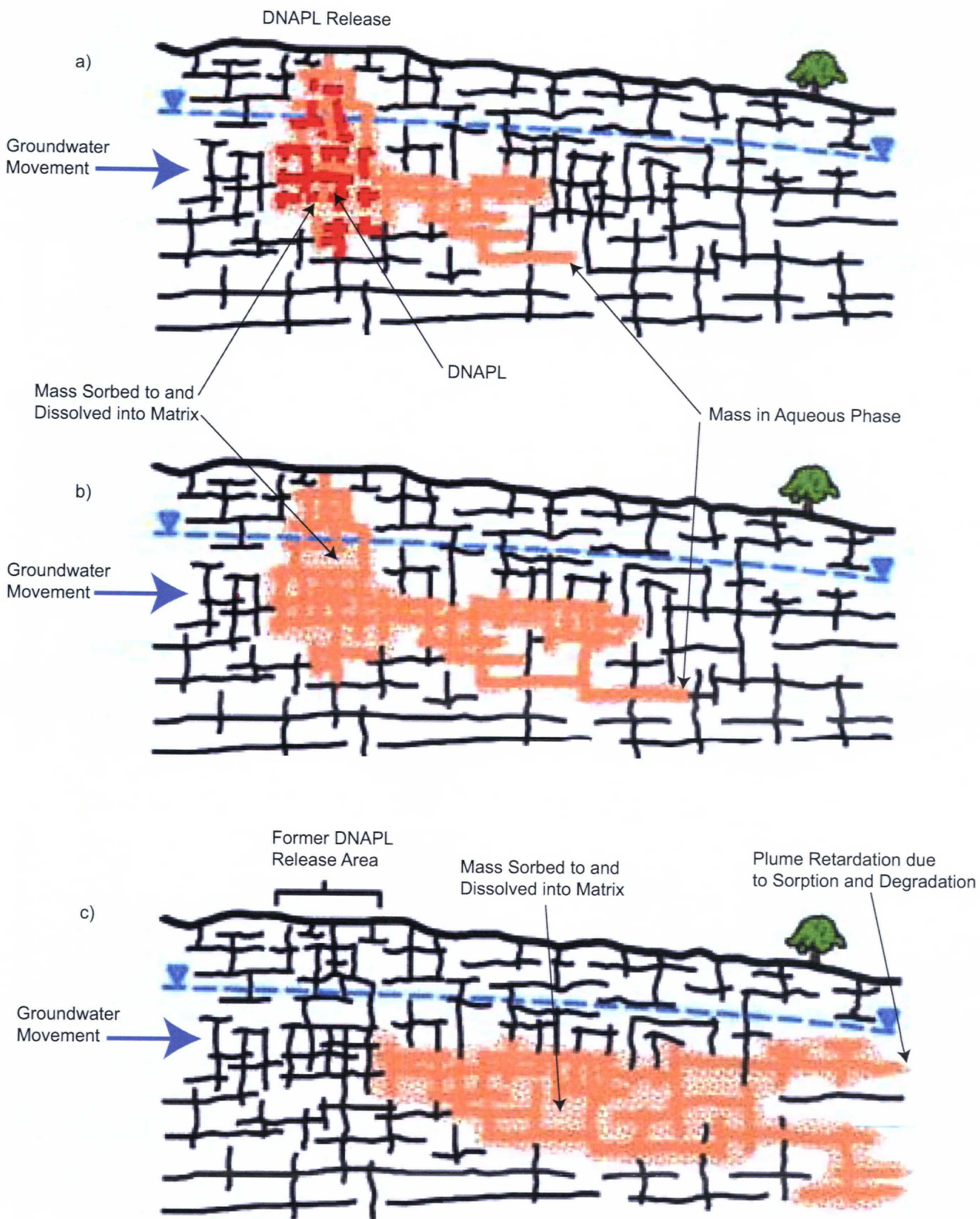



Illustration of the conceptual stages in the evolution of a chlorinated solvent DNAPL release in fractured sedimentary bedrock over time: a) DNAPL flows into the fracture network and begins to dissolve and diffuse into the rock matrix; b) All DNAPL mass has dissolved, and the majority of contaminant mass has diffused into the rock matrix or sorbed onto fracture surfaces; c) Groundwater movement through the fracture network has redistributed the source mass downgradient, the source zone concentrations are decreasing and the plume front is approaching stability. Diffusion, sorption, and degradation continue to affect long term plume stability. (adapted from Parker et al. 2010)

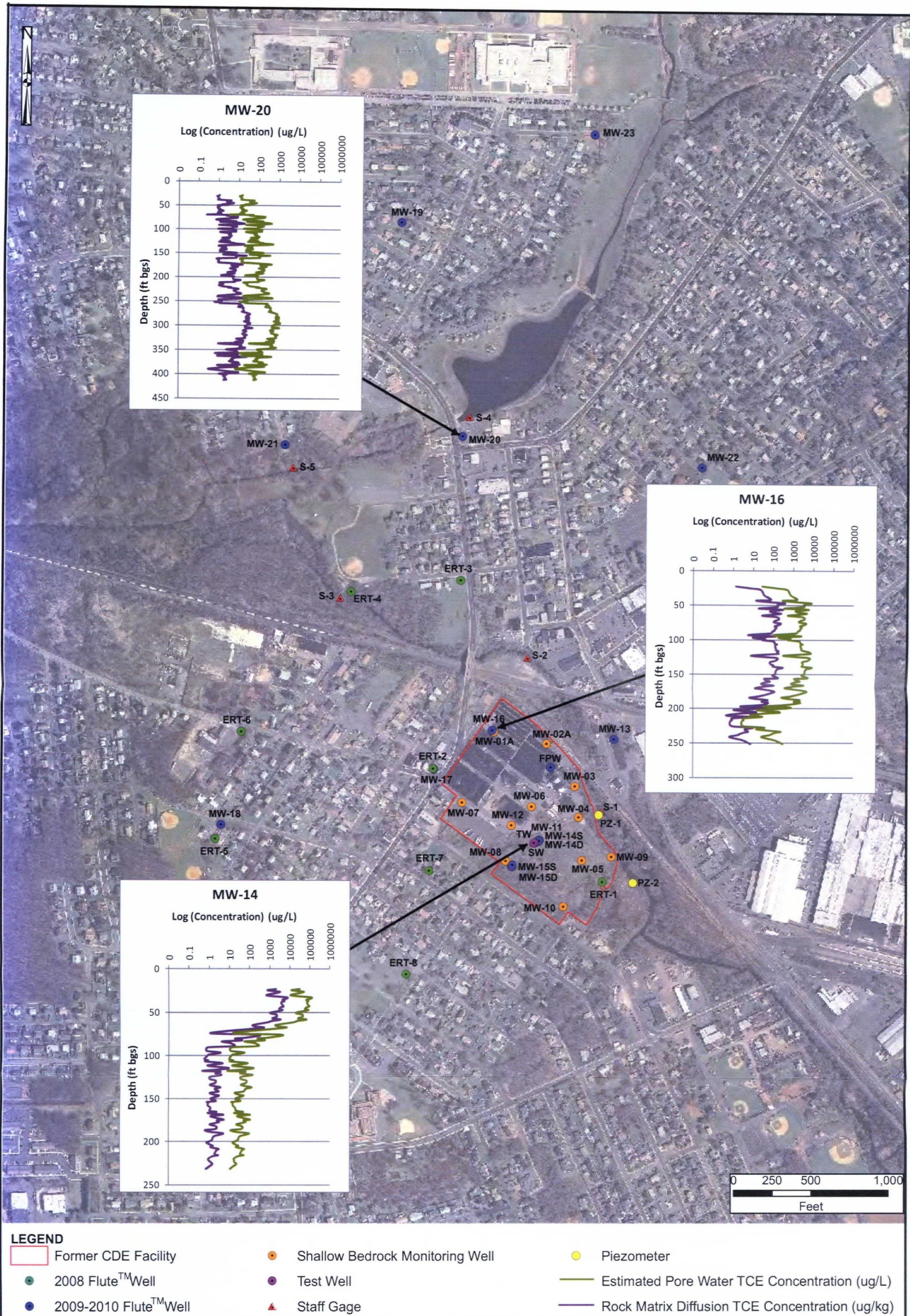
-  Former CDE Facility
  2009-2010 Flute™ Well
  Test Well
  Piezometer
 2008 Flute™ Well
 Shallow Bedrock Monitoring Well
 Staff Gage



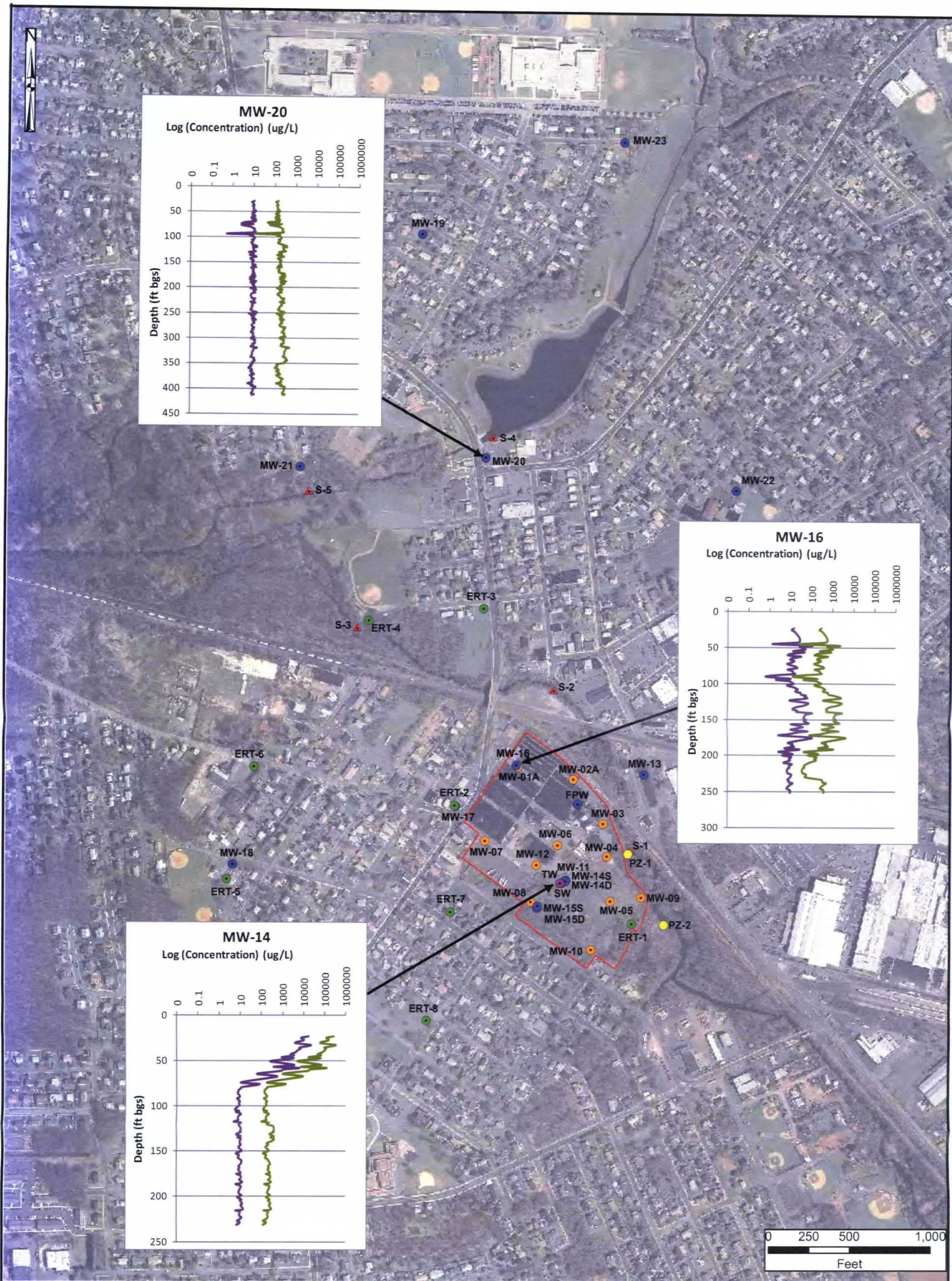
Cornell-Dubilier Electronics
Superfund Site
South Plainfield, New Jersey

Monitoring Well, Test Well, Piezometer, and Staff Gage Locations

FIGURE 2-3

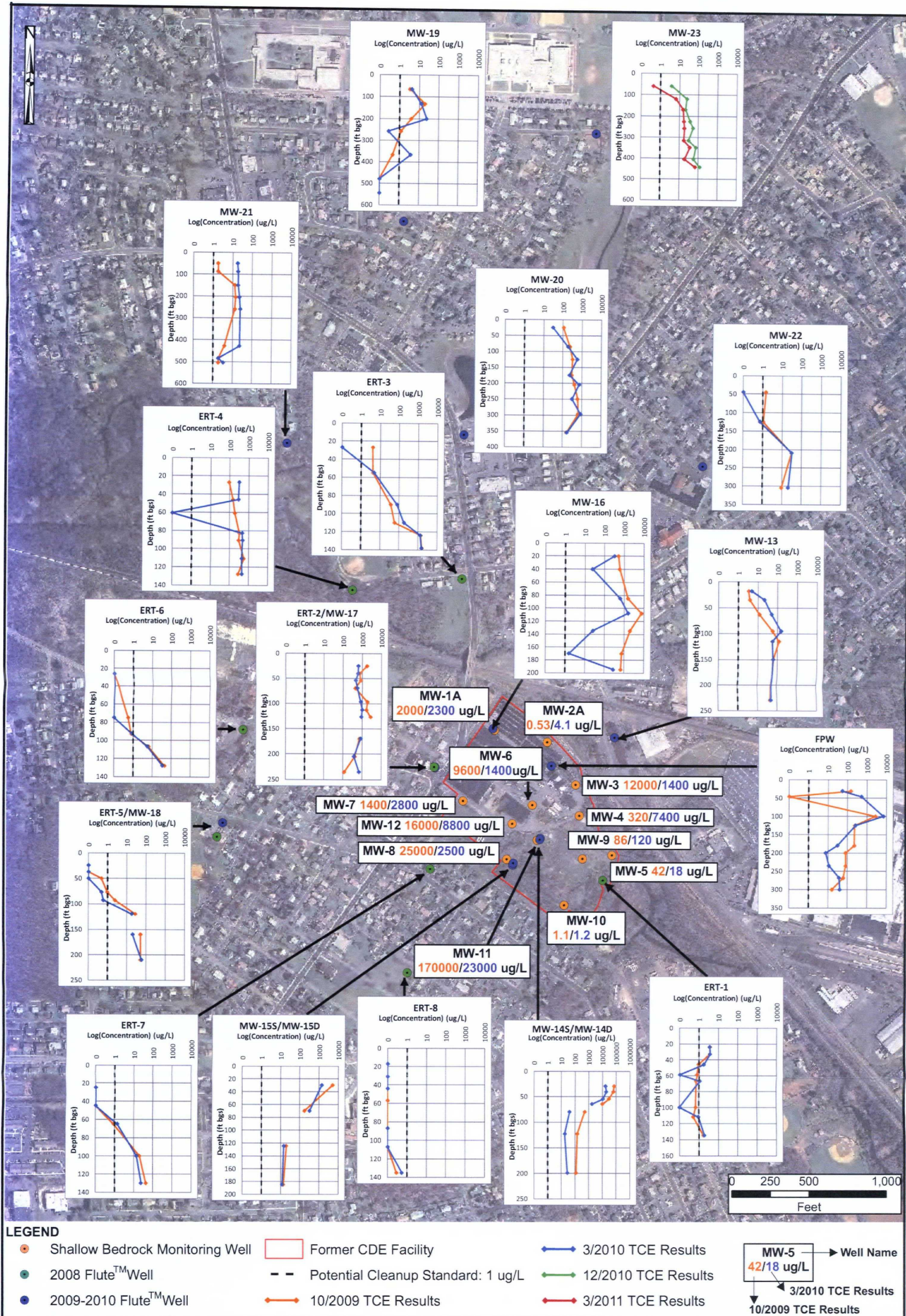


 Cornell-Dubilier Electronics Superfund Site South Plainfield, New Jersey	Pore Water and Rock Matrix Trichloroethene Concentrations	FIGURE 2-4
---	---	------------



LEGEND

Former CDE Facility	Shallow Bedrock Monitoring Well	Piezometer
2008 Flute™ Well	Test Well	Estimated Pore Water cDCE Concentration (ug/L)
2009-2010 Flute™ Well	Staff Gage	Rock Matrix Diffusion cDCE Concentration (ug/kg)



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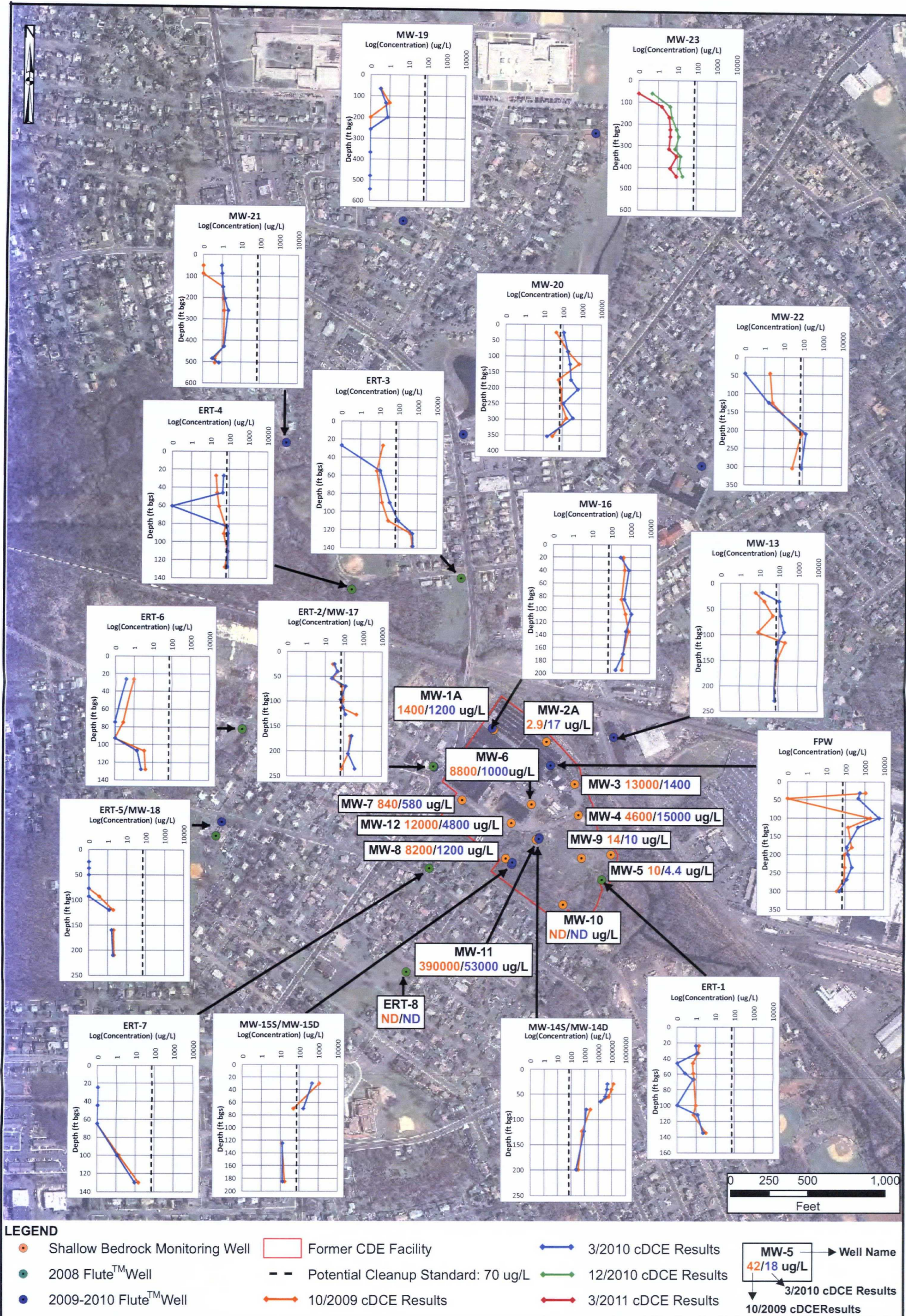


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Superfund Site
South Plainfield, New Jersey

Trichloroethene in Groundwater
2009-2011* Sampling Events

*MW-23 results from 12/2010 and 3/2011

FIGURE 2-6



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Superfund Site
South Plainfield, New Jersey

cis-1,2-Dichloroethene in
Groundwater 2009-2011*
Sampling Events

*MW-23 results from 12/2010 and 3/2011

FIGURE 2-7



Legend

Former CDE Facility

Shallow Bedrock Monitoring Well

*Note: MW-23 installed and sampled in December 2010, March 2011

2008 Flute™ Well

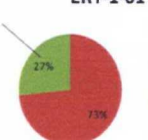
2009 Flute™ Well

Test Well

Staff Gage

Piezometer

Molar Mass %
of Total CVOC
Concentration



Compound
PCE
TCE
c/s DCE +
Trans DCE
VC

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Cornell-Dubilier Electronics
Superfund Site - OU3
South Plainfield, New Jersey

CVOC MOLAR MASS DISTRIBUTION
Shallow Water Bearing Zone
March 2010

Figure 2-8

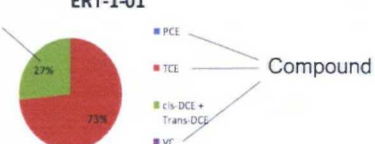


Legend

- Former CDE Facility
- 2008 Flute™ Well
- Test Well
- Piezometer
- Shallow Bedrock Monitoring Well
- 2009 Flute™ Well
- ▲ Staff Gage

*Note: MW-23 installed and sampled in December 2010, March 2011

Molar Mass % of Total CVOC Concentration



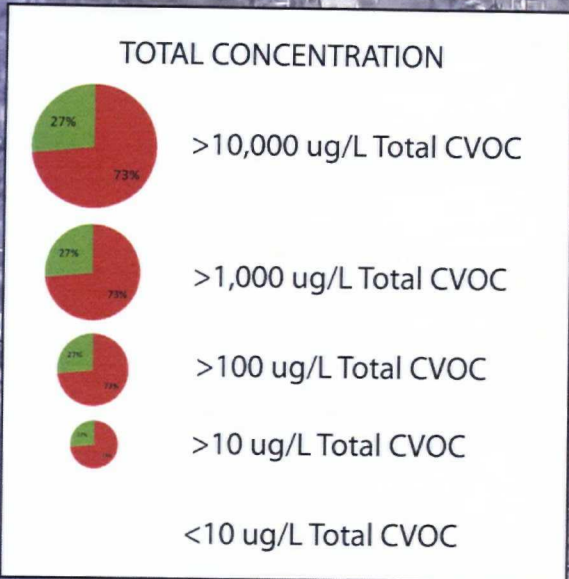
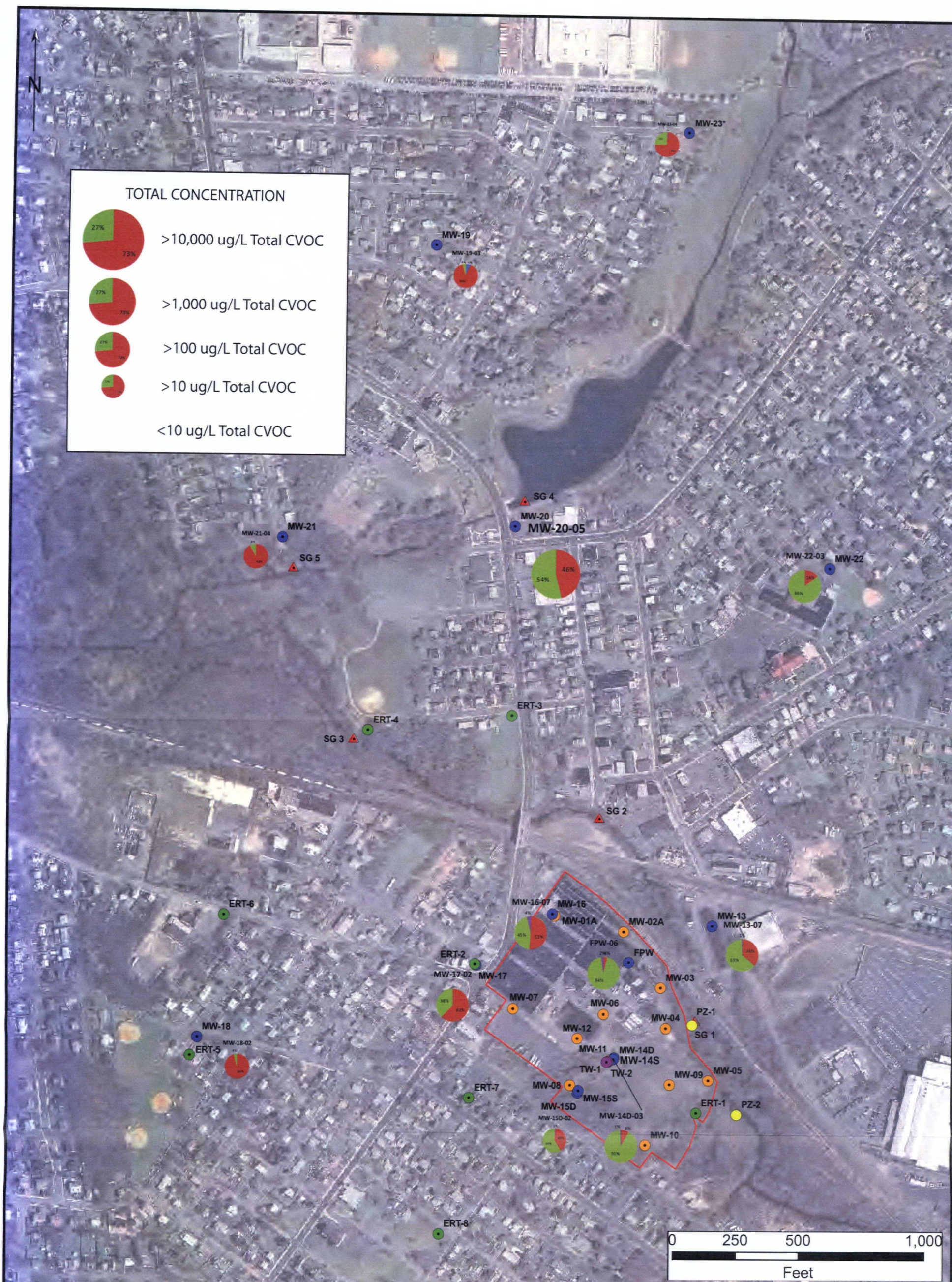
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**Cornell-Dubilier Electronics
Superfund Site - OU3**
South Plainfield, New Jersey

CVOC MOLAR MASS DISTRIBUTION
Intermediate Water Bearing Zone
March 2010

Figure 2-9

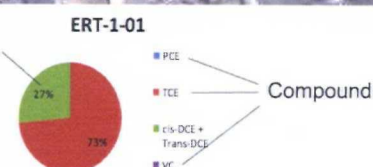


Legend

- Former CDE Facility
- 2008 Flute™ Well
- Test Well
- Piezometer
- Shallow Bedrock Monitoring Well
- 2009 Flute™ Well
- ▲ Staff Gage

*Note: MW-23 installed and sampled in December 2010, March 2011

Molar Mass % of Total CVOC Concentration



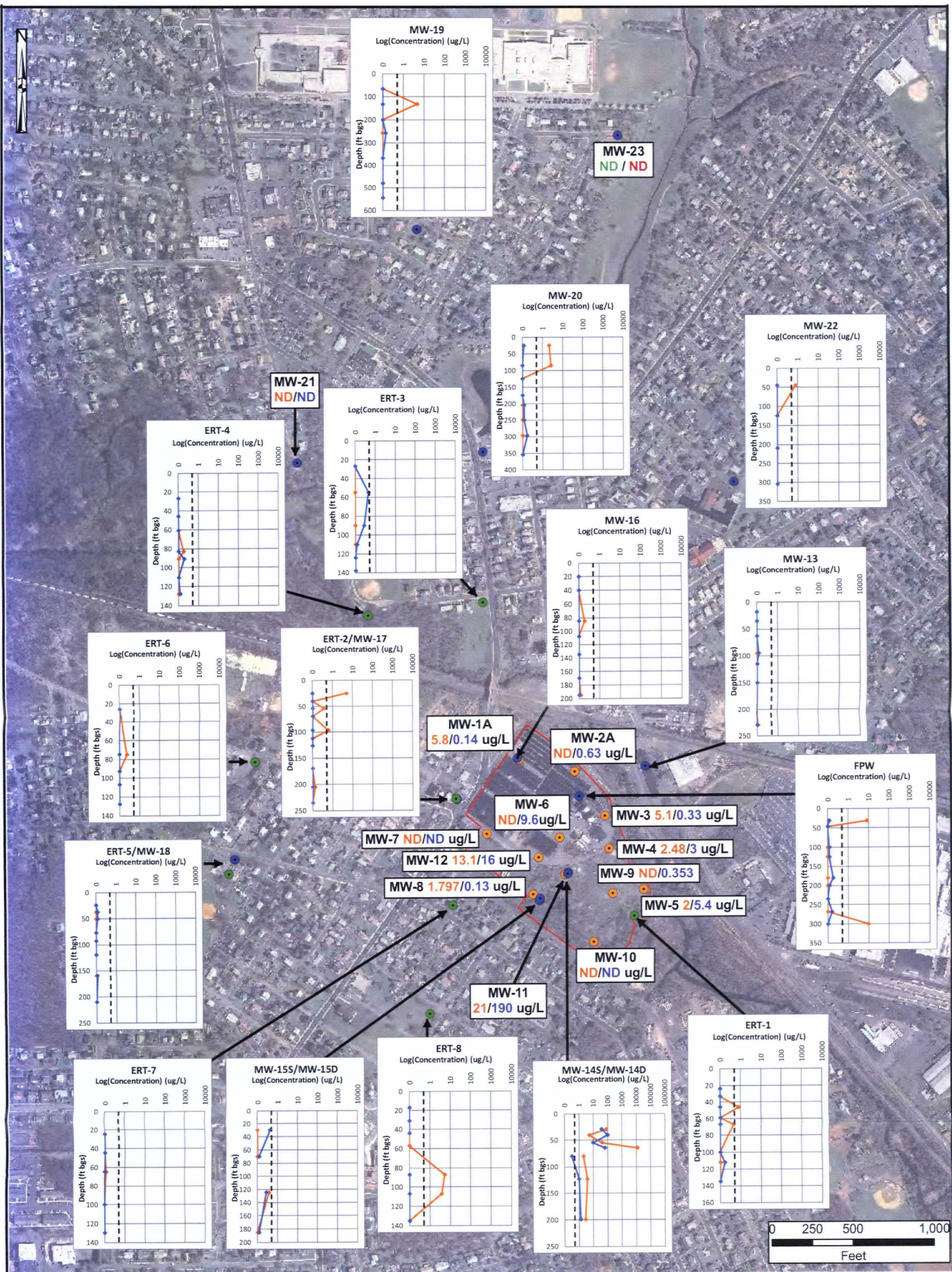
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**Cornell-Dubilier Electronics
Superfund Site - OU3**
South Plainfield, New Jersey

CVOC MOLAR MASS DISTRIBUTION
Deep Water Bearing Zone
March 2010

Figure 2-10



LEGEND

- Shallow Bedrock Monitoring Well
- 2008 Flute™ Well
- 2009-2010 Flute™ Well
- Former CDE Facility
- Potential Cleanup Standard: 0.5 ug/L
- 3/2010 PCB Results
- 12/2010 PCB Results
- 3/2011 PCB Results
- 10/2009 PCB Results

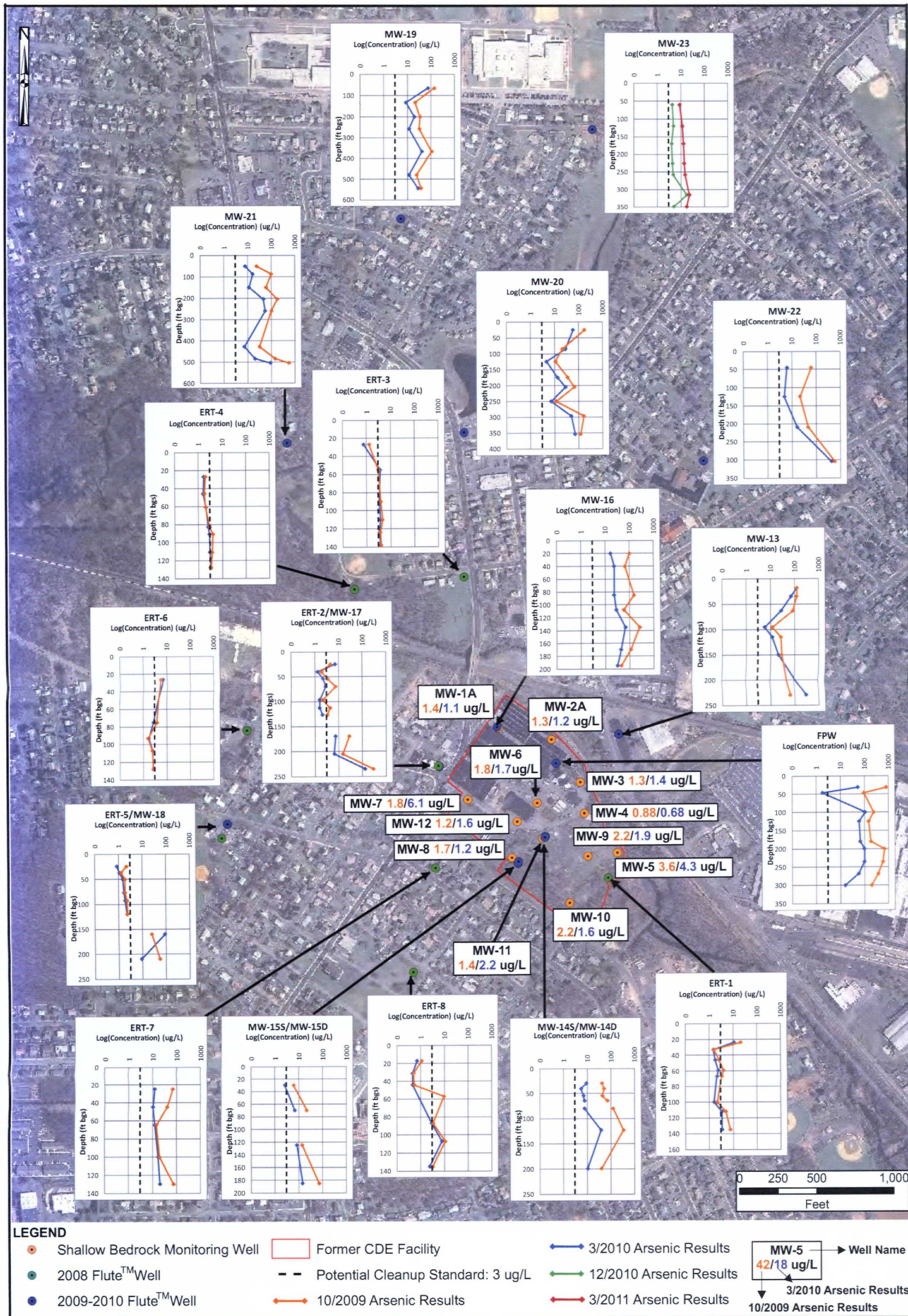
MW-5 → Well Name
42/18 ug/L
↓ 3/2010 PCB Results
↓ 10/2009 PCB Results



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South Plainfield, New Jersey

Total PCB Aroclors in
Groundwater 2009-2011*
Sampling Events
*MW-23 results from 12/2010 and 3/2011

FIGURE 2-11



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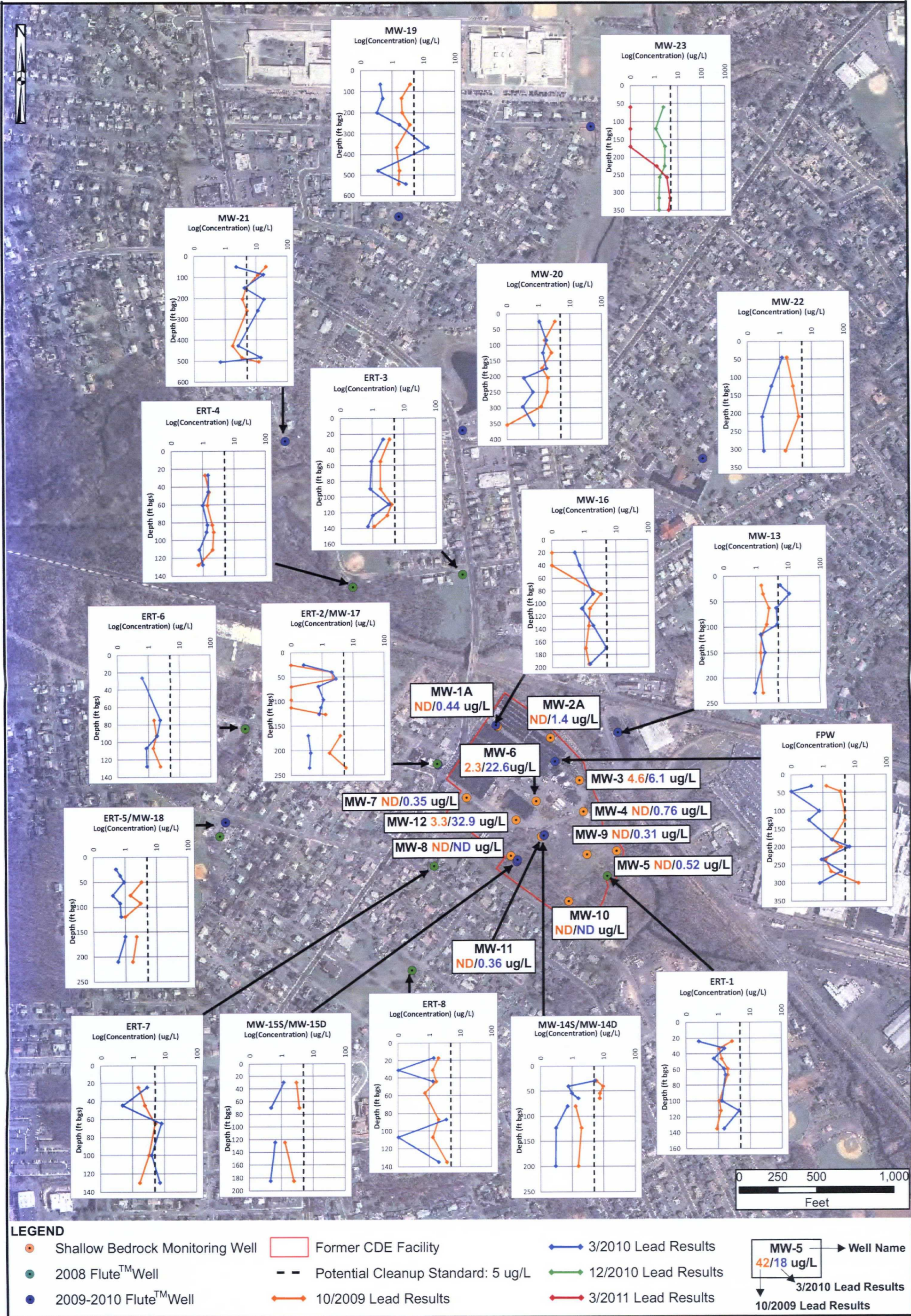


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Superfund Site
South Plainfield, New Jersey

Arsenic in Groundwater
2009-2011* Sampling Events

*MW-23 results from 12/2010 and 3/2011

FIGURE 2-12



Cornell-Dubilier Electronics
Superfund Site
South Plainfield, New Jersey

Lead in Groundwater
2009-2011* Sampling Events

*MW-23 results from 12/2010 and 3/2011

FIGURE 2-13



LEGEND

- Shallow Bedrock Monitoring Well
- 2008 Flute™ Well
- 2009-2010 Flute™ Well

Former CDE Facility

Note 1: Dioxin TEQ could not be calculated.
See RI Report Appendix K.3.

MW-8
0.49/0.86
Well Name
7/2010 Dioxin TEQ Value
3/2010 Dioxin TEQ Value



Cornell-Dubilier Electronics
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South Plainfield, New Jersey

Dioxin Toxicity Equivalents
(TEQs) in Groundwater
March and July 2010 Sampling Events

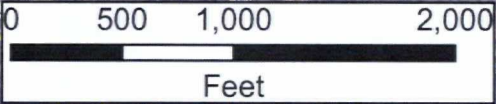
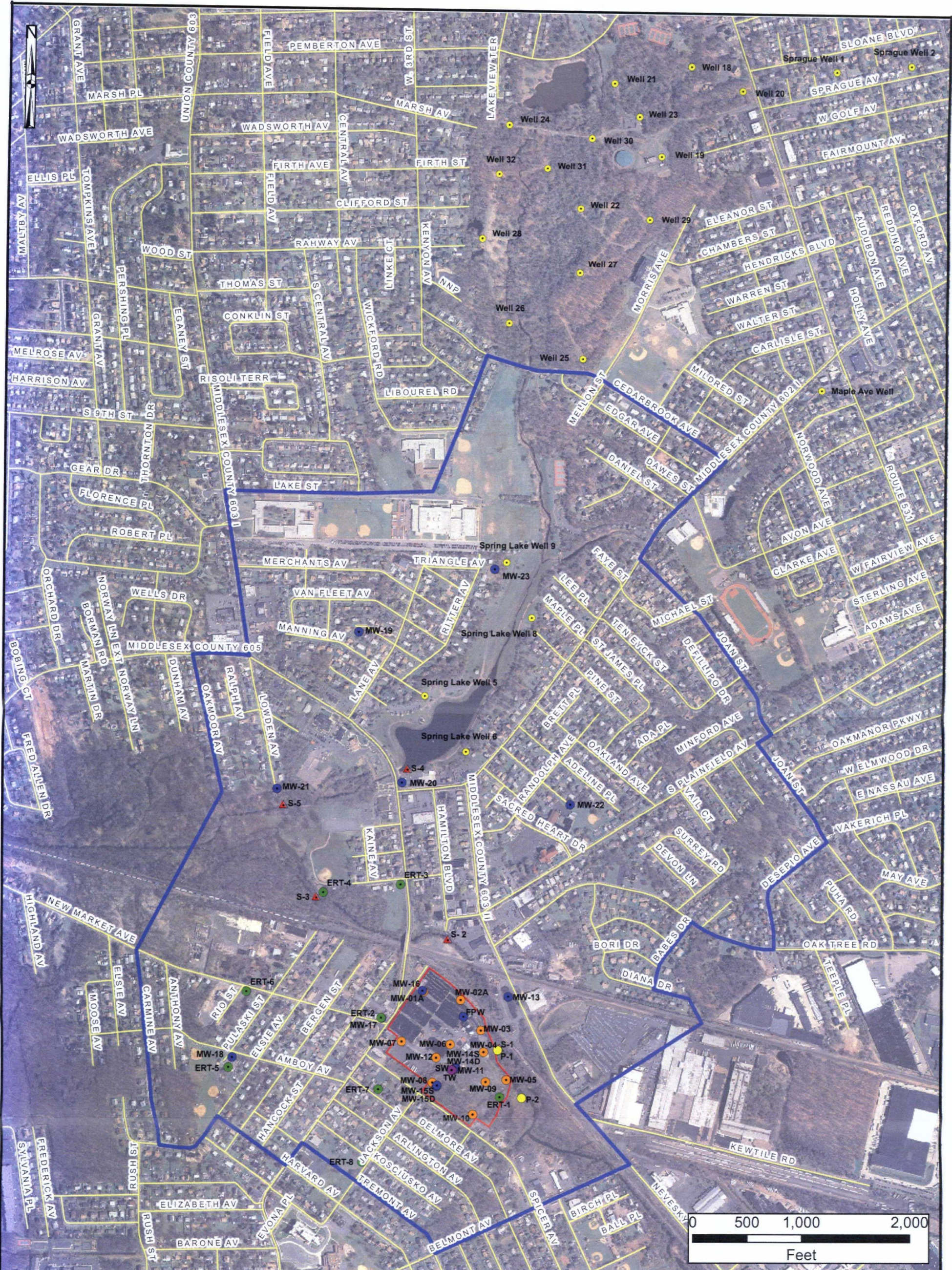
FIGURE 2-14












Cornell-Dubilier Electronics
Superfund Site
South Plainfield, New Jersey

4'4-DDT in Groundwater
2009-2011* Sampling Events
*MW-23 results from 12/2010 and 3/2011

FIGURE 2-15



Legend

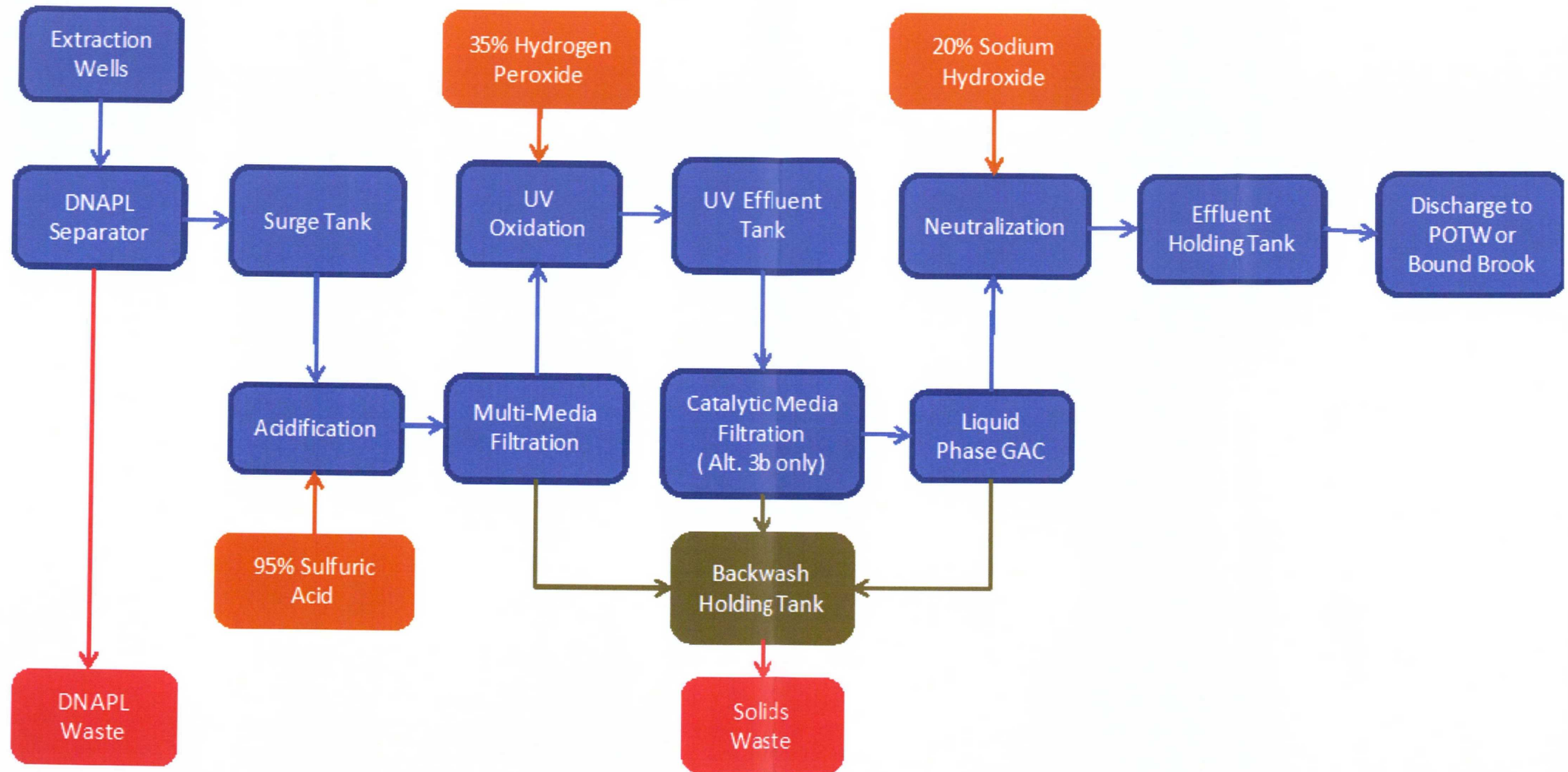
- | | | | | | |
|---|---------------------|---|---------------------------------|---|------------|
|  | Former CDE Facility |  | 2009-2010 Flute™ Well |  | Staff Gage |
|  | TI ZONE |  | Shallow Bedrock Monitoring Well |  | Piezometer |
|  | 2008 Flute™ Well |  | Test Well |  | Roads |



Cornell-Dubilier Electronics
Superfund Site
South Plainfield, New Jersey

PROPOSED TI ZONE

Figure 3-1





Legend

- | | | | |
|--------------------------------------|-----------------------|------------|---------------------|
| Source Area for Alternatives 4, 5, 6 | 2008 Flute™ Well | Test Well | Piezometer |
| Shallow Bedrock Monitoring Well | 2009-2010 Flute™ Well | Staff Gage | Former CDE Facility |



Cornell-Dubilier Electronics
Superfund Site
South Plainfield, New Jersey

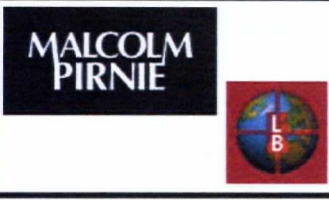
Treatment Area for
Alternatives 4, 5, and 6

FIGURE 5-2



Legend

- | | | | |
|-------------------------------|---------------------------------|-----------------------|------------|
| Treatment Area | Former CDE Facility | 2009-2010 Flute™ Well | Piezometer |
| Injection Point Radii (20 ft) | Shallow Bedrock Monitoring Well | Test Well | |
| Injection Well | 2008 Flute™ Well | Staff Gage | |



Cornell-Dubilier Electronics
Superfund Site
South Plainfield, New Jersey

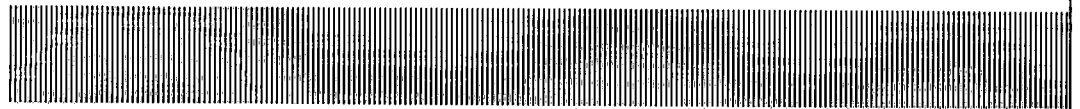
Injection Locations for
Alternative 5

FIGURE 5-3

United States Army Corps of Engineers, Kansas City
Draft Feasibility Study Report
Operable Unit 3: Groundwater
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Appendix A

Draft Report on Discrete Fracture Network (DFN) Contaminant Transport Modeling, Cornell-Dubilier Electronics Superfund Site – OU3 Groundwater



Report on Discrete Fracture Network (DFN) Contaminant Transport Modeling
Cornell-Dubilier Electronics Superfund Site – OU3 Groundwater

Prepared by Steven Chapman, M.Sc.

Reviewed by Dr. Beth Parker and Dr. John Cherry

DRAFT June 30, 2011

OVERVIEW

This report provides an overview of the methodology and results of discrete fracture network (DFN) simulations of contaminant fate and transport at the Cornell-Dubilier Electronics Superfund Site (the CDE site) in South Plainfield, New Jersey. This report is intended to be included as an appendix to the RI/FS reports. The technical memo submitted to EPA in February 2011 outlined the proposed modeling approach, where the bulk groundwater flow system is represented in a MODFLOW equivalent porous media (EPM) model followed by application of a discrete fracture network (DFN) model for assessing contaminant fate and transport in OU3 groundwater. The MODFLOW modeling report is provided separately as an attachment to the RI report. Data collected as part of the site investigations provided the necessary parameters for DFN simulations, including properties of the rock matrix (e.g. porosity, organic carbon content) and fracture network characteristics (e.g. fracture apertures and spacing). DFN simulations incorporate diffusion processes involving transfer of contaminant mass from fractures to the rock matrix, which has important implications for plume attenuation (e.g. Lipson et al., 2005) and remedial efficacy (e.g. Parker et al., 2010).

Included as an attachment to this report are a series of nine short articles on various aspects of the DFN approach for investigation of contaminated sites. Article 1 provides an overview of the DFN approach and the other articles describe various aspects of this approach, several of which have been applied during investigations at the CDE site including: use of rock core VOC analyses (Article 2); use of FLUTE liners for obtaining depth discrete measurements of permeability and for estimation of fracture apertures (Article 3); borehole geophysics (Article 5); and use of multilevel well systems for hydraulic head and groundwater sampling (Article 7). Article 8 provides an overview of the nature of chlorinated organic source zones and plumes in sedimentary rock, which is relevant to the CDE site conditions. Article 9 provides an overview of the DFN modeling approach which is the focus of this report.

EPM-DFN MODELING APPROACH

Pumping tests at the CDE site show that the groundwater flow system in the highly fractured bedrock can be reasonably simulated as an equivalent porous media (EPM). However, evaluation of contaminant fate and transport must consider effects of matrix diffusion on contaminant behavior in discretely fractured rock systems. While fractures provide the dominant pathways for groundwater flow (i.e. fracture porosity, which typically ranges from 10^{-3} to 10^{-5}) the large rock matrix porosity (typically 2-20% in sedimentary rock such as sandstone, siltstone and shale) represents the bulk of the contaminant mass storage capacity. Thus diffusion of contaminants into the rock matrix in this dual porosity system, as well as sorption within the matrix and potentially contaminant degradation, is expected to have a strong influence on contaminant behavior and remedial efficacy. The attached Article 8 provides a more detailed overview of the nature of source zones and plumes in fractured sedimentary rock.

The modeling approach applied at the CDE site involved application of the MODFLOW EPM model to simulate the groundwater flow system to obtain overall bulk flow characteristics (i.e. hydraulic gradients, bulk hydraulic conductivity and groundwater fluxes) and then the discrete fracture network (DFN) model FRACTRAN was used to simulate contaminant fate and transport. Other data collected as part of the RI investigations (e.g. bulk hydraulic conductivity derived from FLUTE liner hydraulic conductivity profiling and pumping tests) also provide insight into the bulk groundwater flow system. Site investigations included application of field and laboratory testing to provide parameter inputs necessary for DFN simulations, including information on fracture apertures and rock matrix parameters. The attached Article 9 provides a more detailed overview of the EPM-DFN modeling approach.

The purpose of the DFN transport simulations is to represent groundwater flow and contaminant transport in fractured porous media incorporating relevant processes of rapid groundwater flow in fractures and contaminant diffusion into and out of the rock matrix. Other work has shown that matrix diffusion and degradation strongly affects contaminant transport in such dual porosity systems, with important implications for plume attenuation (e.g. Lipson et al., 2005) and remedial efficacy (e.g. Parker et al., 2010).

DFN simulations were conducted using the numerical model FRACTRAN, which was developed at the University of Waterloo based on Sudicky and McLaren (1992). FRACTRAN can be used to simulate steady state groundwater flow and transient contaminant transport in discretely fractured rock within a system of orthogonal fractures in 2-D. The model allows incorporation of fracture network geometry and relevant processes that will affect the transport of contaminants via interactions with the rock matrix (e.g. matrix diffusion, sorption, degradation) in discrete fracture networks in a much more realistic way compared to approaches that utilize dual-porosity methods. The National Research Council (NRC, 1996) provides an overview of the various simulation approaches. Deterministic simulations of contaminant transport in fractured rock are clearly not feasible given the complexity of fractured rock systems. However, FRACTRAN simulations can be used to represent site conditions in a 'stylistic' sense and are bounded by real data and incorporate site-specific inputs to the extent possible. Comparisons with field data can be performed, for example, with hydraulic head profiles in multilevel wells and contaminant distribution from multilevel wells and rock core sampling, to examine whether simulations reasonably represent field conditions. Overall this approach in coupling the two models, MODFLOW for the flow system and FRACTRAN for contaminant transport, is expected to provide a much improved understanding of controls on contaminant behavior. It is also a useful tool for assessing remedial options and efficacy.

DFN MODEL SETUP AND PARAMETERS

The FRACTRAN simulations were applied in vertical cross-section representing conditions along the approximate centerline of the plume flowpath. Fracture network characteristics (e.g. fracture network geometry – spacing, lengths and apertures) were constrained by field data to the extent feasible. Fracture spacing was based on core observations and geophysics, and fracture apertures derived from hydraulic testing. Groundwater flow rates and hydraulic conditions in the FRACTRAN DFN simulations were also constrained by the MODFLOW EPM simulations (see the MODFLOW report in the RI Appendix). While the FRACTRAN model is limited to 2-D domains with orthogonal fracture networks, fractures can have variable lengths, apertures and spacing and therefore can incorporate some of the complexity of real fractured rock systems. Following is an overview of parameter measurements on site samples and hydraulic testing data used for designing the DFN simulations. More detailed presentation and analysis of this data is provided in the RI report.

Rock matrix parameters

The hydrogeologic setting of the site is dominated by a dual porosity aquifer comprised of fractured mudstone (Figure 1) with appreciable matrix porosity. Table 1 provides a summary of laboratory physical property measurements performed on forty-one intact samples of rock core retained during the drilling at MW-14, MW-16 and MW-20. Figure 2 shows histograms for selected parameters. Rock matrix porosity (ϕ_m) ranged from 6 to 17% with an average of 10%. Total organic carbon (TOC) content ranged from 0.0025 to 0.033% with an average of 0.010% (excluding one outlier at 0.200% from MW-16). Assuming linear equilibrium sorption with partitioning dominated by organic carbon and using the well-known relation:

$$R = 1 + \frac{\rho_b}{\phi} K_{oc} f_{oc} \quad [1]$$

the estimated retardation factor (R) for TCE is 1.3 applying average values for matrix porosity (ϕ_m), bulk density (ρ_b) and organic carbon content (f_{oc}), which is taken as the TOC value and using a literature organic carbon partitioning coefficient (K_{oc}) of 126 mL/g (from Table A1 of Pankow and Cherry, 1996). Applying values that would provide the highest possible R value (i.e. highest ρ_b and f_{oc} and lowest ϕ) the TCE retardation factor would be 2.8. For the FRACTRAN

DFN simulations an R factor for TCE of 1.5 was assumed. Measurements of rock matrix hydraulic conductivity (K_m) and tortuosity (τ) were not performed on CDE samples, and values of $K_m=1 \times 10^{-8}$ m/sec and $\tau=0.10$ were assumed, which are consistent with literature values.

Fracture Network Characteristics and Bulk Hydraulic Conductivity

FLUTe liner hydraulic conductivity profiling was conducted at 22 corehole locations and results are summarized in Table 2. The attached Article 3 and Keller et al. (2011) provide more details on conducting and interpreting these types of tests, and more details on CDE site tests are provided in the RI report. The tests provided a range in overall bulk hydraulic conductivity (K_b) of nearly two orders of magnitude from 6.5×10^{-7} to 3.3×10^{-5} m/sec (0.2 to 9.2 ft/day) with an average of 7.7×10^{-6} m/sec (2.2 ft/day) and a histogram of the results is provided in Figure 3a. The average K_b is nearly 3 orders of magnitude higher than the estimated rock matrix hydraulic conductivity applied in DFN simulations, which is expected since the bulk hydraulic conductivity of such a highly fractured bedrock system is governed nearly entirely by the interconnected fracture network.

Hydraulic apertures were estimated for discrete features from the dataset by assuming that any sequential transmissivity values in the FLUTe datasets over short vertical intervals were attributed to a single fracture, and transmissivity of this zone was lumped to provide an assumed transmissivity value for the fracture (T_f), using the cubic law:

$$T_f = K_f(2b) = \frac{\rho g (2b)^3}{12\mu} \quad [2]$$

where $2b$ is the hydraulic fracture aperture, K_f is fracture hydraulic conductivity, and μ is water viscosity. It should be noted that use of FLUTe liner profiling data for estimation of apertures for discrete fractures is a recent development, and rigorous review of methods for assessing such datasets to estimate apertures and comparison with more established methods such as packer testing have not yet been conducted. Figure 4 shows a histogram of estimated fracture apertures for all core holes tested, showing an overall range from <5 to 1300 microns with a geometric mean of 74 microns. Bulk fracture porosity (ϕ_f) was then estimated for each of the coreholes tested by summing all of the estimated apertures and then dividing by the length of borehole

tested. These estimates indicate the bulk fracture porosity falls within a relatively narrow range from 1.2×10^{-4} to 5.2×10^{-4} with an average of 2.4×10^{-4} (see histogram in Figure 3b).

The bulk average linear groundwater velocity in the fracture network (\bar{v}_f) can be estimated using a modified version of Darcy's Law:

$$\bar{v}_f = \frac{K_b i}{\phi_f} \quad [3]$$

where K_b is the bulk hydraulic conductivity, i is the hydraulic gradient and ϕ_f is the bulk fracture porosity. This calculation assumes that all flow occurs in the interconnected fracture network, and does not take into account lack of flow in dead-end fractures, flow in the rock matrix, and tortuosity of actual flow paths, and therefore only provides a rough estimate of average flow velocity through the fracture network. Applying the average K_b and ϕ_f values from the FLUTE liner testing and assuming an average hydraulic gradient of 0.3% (see potentiometric surface maps in the RI report and MODFLOW modeling report for more details on hydraulic gradients) provides an average linear groundwater velocity of 8.3 m/day, suggesting rapid groundwater flow rates in fractures. Therefore, in the absence of mass transfer via diffusion to the matrix and other attenuation processes, the plume would have been expected to travel long distances off-site reaching receptors (e.g. pumping wells or surface water) within relatively short periods of time after releases occurred.

Figure 5 shows a more detailed workup of data from one of the cored locations (MW-16). The first column shows fractures observed in cores (classified as 'horizontal', 'high angle' and 'broken zones'), fractures observed via acoustic televiewer (ATV) (classified as 'open' or 'less open') and fractures identified via the FLUTE liner testing. The interpreted FLUTE liner transmissivity profile for MW-16 is shown in the right hand column in Figure 5. At this location, the FLUTE test data apertures were interpreted in two ways, first using the methodology described above where any sequential transmissivity values were attributed to a single fracture, and then using a modified method assuming any transmissivity values falling within a 0.5 ft interval, and including any sequential T values falling outside this interval, were combined assuming a single fracture. The latter method is more conservative in that it yields fewer interpreted fractures and higher apertures (see fracture frequency comparison between the two

methods in Figure 5). However, for the MW-16 dataset the difference in average apertures between these two methods was not that significant, with geometric mean apertures of about 52 and 60 microns for the first and second methods, respectively. The remaining FLUTE liner test datasets were interpreted using the first method only. Figure 5 also shows a comparison of fracture frequency estimated over 10 ft intervals based on core, ATV and FLUTE liner tests. In general it is expected that core data will overestimate in-situ fracture frequency since many of the core breaks observed may be mechanical breaks caused by drilling and extraction of cores from the core barrel, and ATV will generally underestimate fracture frequency due to inability of this technique to image smaller scale features (generally 2 mm resolution with fractures to 0.1 mm). Also, neither core nor ATV provides insight on whether groundwater flow occurs in the identified fractures (i.e. whether they are open with connectivity or closed).

As expected, at MW-16 fracture frequency via cores was generally higher in all intervals compared to the fractures identified with ATV. Fracture frequency derived from the FLUTE liner test data was also lower than that from core observations, particularly for the second method of lumping transmissivity values. Ideally the FLUTE liner test data would identify all permeable features, and it would be expected that core observations would overestimate frequency of transmissive fractures as discussed above. However, as discussed earlier, use of FLUTE liner test data to identify individual features is a recent development. The resolution and ability to identify individual fractures is affected by several factors including: 1) presence of high permeability zones which affects ability to resolve lower permeability zones, 2) time intervals used for logging liner descent, 3) 'noise' in the datasets due to operational variables, 4) borehole conditions (e.g. enlargements) which affect results, 5) assumptions in assigning transmissivity to individual features and transmissivity estimation methods, and 6) complexity of fractured rock systems. Therefore use of this data to assess individual features should be considered approximate and applied with caution.

Bulk groundwater flow conditions for use in the FRACTRAN DFN simulations were constrained based on the calibrated MODFLOW EPM flow model. It is reasonable to assume that an EPM model can provide bulk flow parameters (i.e. hydraulic gradients, bulk hydraulic conductivity and Darcy Flux along the plume flowpath) for conditions of dense, well-interconnected fracture networks. The attached Article 9 provides more details on the combined application of EPM

models for flow and DFN models for contaminant transport. Figure 6 shows some of the MODFLOW results, including a plan view of the simulated potentiometric surface and position of the cross-section along the plume flowpath from the source area (Figure 6a) and flow pathlines in plan view (Figure 6b) and along the cross-section (Figure 6c). More details on this modeling are provided in the MODFLOW groundwater modeling report in the RI Appendices. The FRACTRAN DFN simulations cannot capture all of the complexity of the flow system simulated using MODFLOW, which includes surface water interactions with streams and a lake and historical pumping of various well fields. Thus, attempts were only made to represent average current conditions along the plume centerline, neglecting potential surface water interactions and historical pumping variations at the various well fields, such that simulations focus on longer-distance plume transport assuming current pumping at the Park Avenue well field dominates and would be the ultimate receptor. Based on the MODFLOW EPM flow simulation, groundwater flow conditions along an approximately 1400 m (4500 ft) long flowpath along particle traces released from the source (MW-14S/D) area extending to MW-23 can be represented by an average hydraulic gradient of 0.3% and bulk hydraulic conductivity ranging from 1.4×10^{-6} to 2.5×10^{-5} m/sec (0.4 to 7.0 ft/day) with a weighted average of 1.4×10^{-5} m/sec (4.0 ft/day). This average value is higher than the average estimated from the FLUTE liner tests of 7.7×10^{-6} m/sec (2.2 ft/day) (Table 2), but consistent with the pumping test results (see RI report). This is expected since the MODFLOW results represent larger scale values over the model domain.

Supporting information on bulk hydraulic conductivity of the bedrock from a transmissivity survey by the New Jersey Geologic Survey are summarized below (based on a 5-mile radius search of NJDEP Bureau of Water Allocation (BWA) records requested by Malcolm Pirnie):

- 1) Passaic Formation: mean=1193 ft²/day, range=45-5362 ft²/day, median=675 ft²/day (N=19)
- 2) Brunswick Aquifer: mean=1091 ft²/day, range=45-5362 ft²/day, median=764 ft²/day (N=27)

Assuming a range in well lengths from 300 to 500 ft provides a K_b range of 2.2 to 3.7 ft/day using the mean transmissivity value, and overall range from 0.1 to 18 ft/day applying the range in transmissivity values, which is generally consistent with values from the FLUTE liner testing and pumping test results.

Contaminant Conditions

The attached Article 8 provides an overview of a site conceptual model for chlorinated organic source zones and plumes in sedimentary rock. In this conceptual model, contaminant releases occurred as dense non-aqueous phase liquids (DNAPLs); however over a period of years to decades after releases occurred, the DNAPL mass becomes depleted due to dissolution in groundwater flowing in fractures and diffusion in the rock matrix, such that little to no DNAPL may remain at present time (Parker et al., 1994, 1997). Figure 7 shows estimated disappearance times for diffusion only using the average CDE site rock matrix parameters based on Parker et al., 1994. However, this analysis does not account for DNAPL dissolution in groundwater flowing through fractures, which can significantly decrease the time for DNAPL disappearance (e.g. Vanderkwaak and Sudicky, 1996). Thus, complete disappearance of DNAPL from fractures within a period of years to a few decades following releases is consistent with the rock matrix properties and groundwater flow rates at this site based on the range of fracture apertures estimated from FLUTE liner hydraulic conductivity profiling (i.e. <10 to a few hundred microns).

Rock core profiles of estimated TCE and cis-DCE porewater concentrations are plotted in Figure 8 for coreholes MW-14, MW-16 and MW-20, which represent conditions within the suspected source zone (MW-14) and at approximately 250 m (MW-16) and 800 m (MW-20) downgradient. Porewater concentrations were estimated from the total mass concentrations using partitioning calculations based on the rock matrix parameters and sorption estimates (more details are provided in the Stone Environmental report in the RI report appendices). The profiles in Figure 8 also show groundwater concentrations from two sampling episodes from the FLUTE multilevel wells (described by Cherry et al., 2007) later installed in these core holes.

Evidence for complete or nearly complete DNAPL disappearance is supported by rock core data collected from the suspected source area (combined profile from MW-14S/D; Figure 8) showing all estimated porewater TCE concentrations are below the aqueous solubility limit (~1100 mg/L; from Pankow and Cherry, 1996) with a maximum TCE of about 150 mg/L at 33 ft bgs (~13% of solubility) and most values one or more orders of magnitude below solubility. Similarly groundwater concentrations in the FLUTE multilevel well at this location were well-below solubility, with a maximum TCE concentration of 72 mg/L in the shallowest port (30-35 ft bgs). Recent observations suggested presence of residual DNAPL in the overburden in the area of

MW-14S/D, which was apparently mobilized into MW-14D based on NAPL reactive liner testing (see RI report for more details). However the groundwater and rock core data both do not support ongoing substantial DNAPL presence in bedrock, except for minor amounts that may have been mobilized into bedrock from investigation activities at MW-14S/D. Efforts were subsequently made to remove residual DNAPL in the overburden in this area via excavations to the bedrock surface (see RI report). Based on the strong concentration declines with depth at MW-14 based on both in the rock core data and FLUTE multilevel well groundwater data, it appears DNAPL penetration into bedrock may have been limited to the upper bedrock zone (i.e. upper 40 ft or less of bedrock). This limited penetration may have been controlled both by high horizontal fracture frequency and also by limited DNAPL release volumes. The RI report provides more information on site history and what is known about historical releases at the site. Recent remedial activities at the site have focused on removal of contaminated overburden to top of bedrock in the MW-14 area, as discussed more in the RI report.

The FRACTRAN DFN simulations were conducted for TCE only assuming no degradation, although FRACTRAN can accommodate first-order decay. Data from the site suggest transformation of TCE to cis-DCE occurs, but it is unknown whether much further dechlorination occurs since groundwater data shows little VC presence. More details on contaminant conditions are provided in the RI report. Therefore when comparing the FRACTRAN simulation data with field concentration data, the field data were converted to equivalent total TCE concentrations, assuming all cis-DCE observed was produced from TCE transformation, using the relation:

$$[Total\ TCE] = [TCE] + 1.35 [cis - DCE] \quad [4]$$

which corrects for the difference in molecular weights.

The FRACTRAN simulation results are assessed via: 1) 'stylistic' comparisons with total equivalent TCE based on the rock core VOC results at MW-14, MW-16 and MW-20 (Figure 9a) along the approximate plume centerline, and comparison with maximum observed concentrations versus distance based on both the rock core data and groundwater sampling data (Figure 9b). Both of these datasets show apparently strong attenuation in equivalent TCE concentrations with distance from the site. Maximum rock core equivalent TCE declines by nearly 3 orders of magnitude (OM) over the 800 m (~2600 ft) distance between MW-14 and

MW-20. Similarly, maximum equivalent TCE in groundwater declines by about 30M between the source (MW-14) area and furthest downgradient monitoring well MW-23 positioned about 1400 m (~4600 ft) downgradient (north), with maximum equivalent TCE of about 150 µg/L.

Included in Figure 9b are projections of the field concentration data using the maximum estimated equivalent porewater TCE data from rock core, and the maximum equivalent groundwater TCE concentrations from multilevel wells (using only the highest concentration data from multilevel wells positioned along the inferred plume flowpath), beyond the distance of the Park Avenue well field, which is located approximately 2200 m (~7200 ft) downgradient. This simple analysis suggests it is possible that TCE emanating from the CDE site has not reached the well field at concentrations exceeding the MCL, although such projections are very uncertain given the complexity of fractured rock systems. Further interpretation of plume extent is provided in the RI report. It is expected that strong plume attenuation will occur due to diffusive mass transfer from groundwater flowing in fractures to the rock matrix (e.g. see attached Article 8; Lipson et al., 2005). The results of the FRACTRAN DFN simulations tailored to site conditions that follow can be used to assess the reasonableness of such projections.

FRACTRAN DFN SIMULATIONS

FRACTRAN Model Setup and Flow System

In FRACTRAN, the model domain (Figure 10a) for CDE site simulations is a vertical cross-section 1000 m long and 150 m high. The fracture network was selected after attempting several realizations of randomly generated fracture networks and adjusting the key fracture network statistics including mean fracture aperture and variance (Figure 11), fracture density and fracture length ranges to provide an overall horizontal bulk hydraulic conductivity within a target range based on the field data (e.g. FLUTE liner test data and pump test data) and MODFLOW EPM flow model results. Average hydraulic gradients in the FRACTRAN simulation were set to 0.3% (horizontal) and 0.3% vertical (downward) using constant head boundaries applied on all four sides of the domain. The average horizontal hydraulic gradient applied is consistent with the field head distribution and MODFLOW EPM flow system results (e.g. see Figure 6a). As described earlier, the FRACTRAN simulations cannot capture the full flow system complexity in the MODFLOW simulations including surface water interactions and effects of pumping of various well fields. The vertical head component was set to match the apparent plume deepening with depth based on the rock core VOC results (Figure 8, Figure 9a).

Based on steady state flow simulation results (e.g. see head distribution in Figure 12 for the final fracture network and boundary conditions selected) the horizontal K_b of the fractured rock system can be estimated using:

$$Q = K_b i A \rightarrow K_b = \frac{Q}{i A} \quad [5]$$

where Q is the total simulated horizontal flow obtained by averaging inflow and outflow at the LHS and RHS of the model domain, respectively, or crossing the mid-point plane at $X=500$ m, and using the average horizontal hydraulic gradient (i) of 0.3% and cross-sectional area for flow (A) which is the 150 m domain height multiplied by unit thickness. Following flow simulations for several realizations, the selected fracture network (Figure 10a) has an overall horizontal K_b of 5.7×10^{-6} m/sec (1.6 ft/day), which is about 25% lower than the average determined from FLUTE liner testing (7.7×10^{-6} m/sec) and a factor of 2.5 lower than the mean from the calibrated MODFLOW EPM model (1.4×10^{-5} m/sec). The overall bulk fracture porosity (ϕ_f) of this fracture network is 1.5×10^{-4} (horizontal fractures $\sim 1.2 \times 10^{-4}$, vertical fractures $\sim 0.3 \times 10^{-4}$), which is lower

than the estimates from the FLUTE liner test data (average of 2.4×10^{-4}). This is expected based on the lower fracture density in the FRACTRAN generated fracture network. Justification for using a lower K_b for the model compared to field conditions is provided below.

While the FRACTRAN network has a relatively high fracture density, it is lower than the actual site fracture frequency (e.g. see Figure 5). Figure 10b shows example profiles of fracture positions and apertures along two vertical sections ($X=250$ m and 800 m), indicating an average fracture frequency of about 0.85 fractures per m (0.26 fractures per ft). Apertures in the FRACTRAN network (Figure 10a) are log-normally distributed with a geometric mean of 120 microns (Figure 11), which is higher than the mean from the FLUTE liner tests of 74 microns (Figure 4). The higher aperture applied in generation of the FRACTRAN network offsets the lower fracture density to increase the overall K_b . Incorporation of a higher fracture density was not feasible with the current version of FRACTRAN due to the higher grid discretization requirements. Together, the use of lower fracture density and higher mean apertures in the FRACTRAN simulations is expected to cause more rapid plume transport, and therefore a target K_b at the lower end of field estimates from FLUTE liner testing and pumping tests and applied in the MODFLOW EPM model was used to offset this effect. Applying the horizontal K_b , i and horizontal ϕ_f of the FRACTRAN network to estimate an average linear groundwater velocity in the fracture network using Equation 3 provides a value of about 12.3 m/day, which is larger than estimate based on the FLUTE data (8.3 m/day). The FRACTRAN network (Figure 10a) has lower fracture density and bulk fracture porosity compared to field estimates and higher mean apertures. The alternative method of lumping transmissivity values from the FLUTE liner test data, described above for MW-16, would provide a higher mean aperture and lower fracture frequency somewhat more in line with the FRACTRAN network. Despite the FRACTRAN network having lower K_b compared to the field estimates based on the FLUTE liner test data and pumping tests, the FRACTRAN network still has a larger average linear groundwater velocity due to the lower ϕ_f . This suggests potential for the FRACTRAN simulations to overestimate rates of plume transport compared to the field conditions.

FRACTRAN Contaminant Transport Simulations

In the FRACTRAN DFN simulations, the 'source zone' was positioned within the upper portion of the model domain (Figure 10a) consistent with the apparently limited DNAPL penetration. For simulation purposes it is assumed that DNAPL releases occurred about 50 years ago based on site history (described in the RI report), although earlier releases may also have occurred. The source input was assumed constant at aqueous solubility for a period of 20 years, representing a conservative estimate of the time for complete DNAPL disappearance, followed by a period of sustained input at 10% of solubility to present time, representing dissolution of remnant DNAPL in overburden (which presumably occurred in isolated zones) causing ongoing mass input into the upper bedrock zone.

Results of the FRACTRAN transport simulation are plotted in Figure 13 for times of 10, 25 and 50 years (with the latter assumed to represent near present time when rock core sampling was conducted to obtain the profiles shown in Figure 8(2009). FRACTRAN concentrations are plotted as relative concentrations assuming $C_0=1.0$ represents TCE aqueous solubility (~1100 mg/L). Profile results provided later are converted to aqueous concentrations by multiplying by this solubility value. The FRACTRAN results show a range in concentrations spanning 5 orders of magnitude, consistent with the difference between TCE solubility and its MCL (0.005 mg/L). As indicated by the DFN transport simulation results, contaminant migration in the fracture network is much slower than groundwater flow rates in fractures, due to attenuation processes including diffusion of mass from fractures to the rock matrix. However, by 10 years, the simulation results show contamination has already reached the model boundary at 1000 m, and by 50 years contamination occurs throughout the model domain. Ideally the FRACTRAN fracture network would be extended a sufficient distance to capture the full extent of plume transport and provide insight into the distance and rates of plume front migration (e.g. to assess whether contamination from the CDE site may have reached downgradient well fields). However, given the high fracture density and requirements for fine grid discretization to resolve diffusion processes in the matrix, it was necessary to limit the domain size so the code could be compiled with necessary array sizes. The grid for the current network contains nearly 4 million nodes ($NX=3036$, $NZ=1280$) and 600,000 line elements representing the fractures. There are

plans to modify the code so larger arrays can be handled, which would allow the model domain to be extended and still incorporate a similar fracture density, but this is not yet available.

Figure 14 shows a comparison of the FRACTRAN simulated profiles at $X=10$, 250 and 800 m with the field rock core profiles at similar distances at MW-14, MW-16 and MW-20 (note different X-axis scales for simulated and field profiles at MW-16 and MW-20). FRACTRAN concentrations were converted from relative to aqueous concentrations by assuming $C_0=1.0$ represents TCE aqueous solubility. The field rock core profiles show estimated total equivalent TCE concentrations using partitioning calculations to estimate porewater TCE and cis-DCE concentrations (see RI report for more details) and then applying Equation 4. This comparison shows very good “stylistic” agreement between the FRACTRAN simulation results and field rock core profiles. For the source area ($X=10$ m versus MW-14) the concentration distributions and magnitudes are relatively similar, with the rock core profiles showing higher concentrations in a couple of samples adjacent to fractures. A short distance downgradient ($X=250$ m versus MW-16) the contaminant distributions are again quite similar stylistically, but FRACTRAN results overestimate the magnitude of the concentrations, with the concentration scale for the FRACTRAN spanning a range 5X greater than for the MW-16 profile. This is also the case further downgradient ($X=800$ m versus MW-20) where the concentration scale for FRACTRAN profile spans a range 10X greater than for the MW-20 profile. It should be noted that these results are for one realization of a random fracture network; profiles would be expected to vary for different realizations, but overall transport distances and migration rates should be fairly similar between realizations for fracture networks generated using the same fracture network statistics. Figure 15 shows a comparison of the maximum equivalent TCE concentrations versus distance for the field data (rock core VOC profiles and groundwater samples from multilevel wells along the approximate plume centerline) versus the FRACTRAN results at 50 years. The results are consistent in that they all show strong attenuation in maximum concentrations with distance downgradient from the source area. The FRACTRAN results are generally expected to be conservative (i.e. produce more rapid downgradient plume transport and higher downgradient concentrations compared to field conditions) based on a number of the FRACTRAN assumptions and factors not included in these DFN simulations, including:

- 1) FRACTRAN simulations are for a 2-D vertical cross-section domain, which:

- a. assumes an infinitely wide source, which is not the case (see RI report for evidence of a fairly localized source in the MW-14 area);
 - b. neglects plume spreading in the transverse direction, which would have the effect of reducing concentrations downgradient due to increased mixing in the fracture network (i.e. between fractures having higher and lower concentrations) and increased attenuation due to matrix diffusion since the transverse spreading would increase the fracture-matrix contact area;
- 2) As discussed above the selected fracture network for the FRACTRAN simulations has a lower fracture frequency and higher mean apertures compared to field estimates (due to numerical limitations) and therefore these conditions would be expected to produce more rapid rates of plume migration. To some extent this effect was offset by using an overall lower K_b for the FRACTRAN fracture network, but the average groundwater velocity in the fracture network is still larger for the simulated scenario;
- 3) Simulations assume a constant source input for 20-year duration, in reality DNAPL may have disappeared from many fractures sooner than this causing reduced contaminant loading over time compared to the assumptions in the FRACTRAN simulation;
- 4) Simulations neglect degradation effects (but compare to equivalent total TCE based on TCE and cis-DCE concentrations) so any further degradation occurring is not reflected in the FRACTRAN simulations, and even very slow degradation rates can have strong attenuation effects when combined with matrix diffusion;
- 5) Simulations neglect flow system transience (e.g. due to variable pumping at different well fields over time) which is expected to have caused additional plume spreading and increased attenuation due to more contact area for matrix diffusion and more tortuous flow paths;
- 6) The maximum concentrations extracted from FRACTRAN simulations are actual 'point' concentrations, whereas field concentrations from monitoring wells or multilevel well ports are 'blended' values over larger vertical intervals.

Overall the FRACTRAN transport simulation results confirm the strong attenuation inferred based on the field data, showing matrix diffusion effects can account for such strong plume attenuation when combined with a finite source input. Given that the majority of contaminant mass now occurs in the rock matrix, mass discharge in downgradient portions of the plume may

be relatively small. For example, based on the FRACTRAN results, the mass discharge in the downgradient portion of the plume at $X=800$ m at 50 years was assessed. Figure 16 shows profiles of fracture apertures, groundwater flow rates and concentration profiles at 50 years. Mass discharge within the plume across this plane was estimated by multiplying the nodal groundwater flow rates and concentrations and summing over the entire thickness. This provides an estimated TCE mass discharge at 50 years of about 0.3 kg/year per m width (since model domain is a vertical cross-section with unit thickness). With expectations of strong attenuation with distance, mass discharge would be significantly lower than this further downgradient, so that even if TCE contamination from the site has reached the Park Avenue well field, the resulting increase in concentrations may be very small when dilution effects from pumping are factored in.

Future Projection Scenarios

For future projections, two scenarios were assumed: (1) continued input at 10% of solubility, and (2) complete removal of the source input term. The latter scenario is consistent with the recent remedial efforts focused on contaminated overburden removal, assuming any remnant DNAPL in overburden is successfully removed and no longer contributes mass to the bedrock system. This could also represent a scenario where not all DNAPL is removed, but where a source zone hydraulic control system is put in place where any contaminant mass emanating from the source zone is captured and treated. Figure 17 shows simulated concentration contours for these two scenarios of continued source mass input versus complete removal of source mass input at times of 50, 100 and 150 years from present. The results show little impact of complete removal of source mass input on persistence of the downgradient plume, which is expected given that the majority of the contaminant mass exists in the rock matrix. Some minor improvements in internal plume water quality are evident, which are shown more clearly in the plume profile comparisons in Figure 18 at $X=10$ m, 250 m and 800 m. In these plots the "MNA" scenario assumes continued input while the "Source Removal" scenario assumes no continued input due either to complete removal of all DNAPL in overburden or hydraulic cutoff. While some minor improvements in groundwater quality internally within the plume are achieved from complete source removal or cutoff, the time to achieve such benefits are more than 100 years.

Actual source conditions at the CDE site are likely in between these two end points given recent efforts to remove contaminated overburden materials. While these FRACTRAN DFN simulations do not incorporate a sufficiently large domain to capture the full simulated plume extent, the expectation is that the rate of plume front migration would be very slow at present time due to effects of matrix diffusion. These simulations also suggest efforts to completely remove source inputs would have negligible impact on conditions nearer the plume front within any reasonable timeframe. Similar types of scenarios where a larger zone close to the former source is fully remediated (e.g. which could represent aggressive thermal treatment) are provided by Parker et al. (2010) which shows similar results of only minor improvements in downgradient water quality after extended periods of time and little to no effect on the plume front. Inclusion of slow degradation in simulations, if evidence suggests complete dechlorination were occurring in OU3 groundwater, would show more of an effect on the plume following source depletion or cutoff. However this does not seem to be justified based on site data collected to date, but could be examined in future simulations.

CONCLUSIONS

Overall, the FRACTRAN DFN simulations, tailored to site conditions to the extent feasible with the flow system constrained by the MODFLOW EPM results, show that matrix diffusion is expected to have strongly attenuated plume transport at the CDE site. This supports the field data showing strong declines in contaminant concentrations with distance from the site. Results indicate the majority of contaminant mass is now present in the rock matrix, such that mass discharge within the plume in fractures which carry the bulk of groundwater flow should be relatively low. The mass distribution also has significant implications for source zone and plume remediation efficacy. More interpretation of these results will be provided in the RI/FS reports.

REFERENCES

- Cherry, J.A., B.L. Parker, and C. Keller. 2007. A new depth-discrete multilevel monitoring approach for fractured rock. *Ground Water Monitoring & Remediation* 27(2), 57-70.
- Lipson, D.S., Kueper, B.H., Gefell, M.J. 2005. Matrix diffusion-derived plume attenuation in fractured bedrock. *Ground Water*, 43(1), 30-39.
- Keller, C.E., J.A. Cherry and B.L. Parker. 2011. New method for continuous hydraulic conductivity profiling in fractured rock. In submission to *Ground Water*.
- National Research Council (NRC), 1996. *Rock Fractures and Fluid Flow: Contemporary Understanding and Applications*. National Academy Press, Washington, D.C.
- Parker, B.L., R.W. Gillham and J.A. Cherry. 1994. Diffusive disappearance of immiscible-phase organic liquids in fractured geologic media. *Ground Water* 32(5), 805-820.
- Parker, B.L., D.B. McWhorter, and J.A. Cherry. 1997. Diffusive Loss of Non-Aqueous Phase Organic Solvents from Idealized Fracture Networks in Geologic Media. *Ground Water* 35(6), 1077-1088.
- Parker, B.L., Chapman, S.W., and Cherry, J.A. 2010. Plume persistence in fractured sedimentary rock after source zone removal. *Ground Water*, 48(6), 799-803.
- Pankow, J.F., and Cherry, J.A. (eds). 1996. *Dense Chlorinated Solvents and other DNAPLs in Groundwater*. Waterloo Press, Portland, Oregon, 522 pp.
- Sudicky, E.A. and R.G. McLaren. 1992. The Laplace Transform Galerkin Technique for large-scale simulation of mass transport in discretely fractured porous formations. *Water Resources Research*, 28(2), 499-514.
- Vanderkwaak, J.A., and E.A. Sudicky. 1996. Dissolution of non-aqueous phase liquids and aqueous-phase contaminant transport in discretely-fractured porous media. *Journal of Contaminant Hydrology*, 23, 45-68.

FIGURES

(a) MW-14 (Run#10, 64-69 ft bgs)



(b) MW-14 (Run#11, 73-78 ft bgs)



(c) MW-20 (Run#27, 158-163 ft bgs)



Figure 1. Representative core photos from the CDE site cores: (a) MW-14, Run# 10 (64-69 ft bgs), (b) MW-14, Run# 11, 73-78 ft), (c) MW-20, Run#27 (158-163 ft bgs).

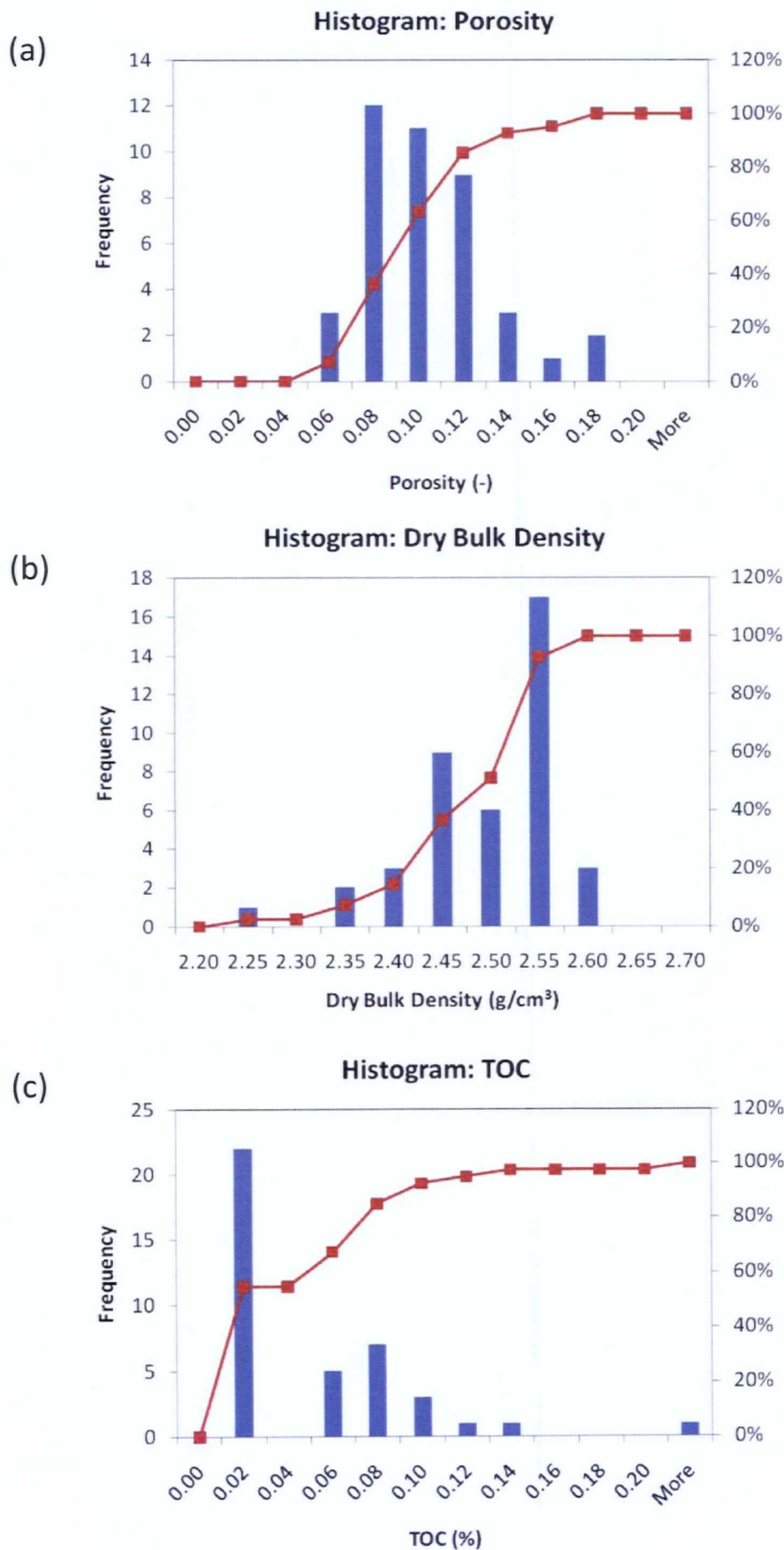
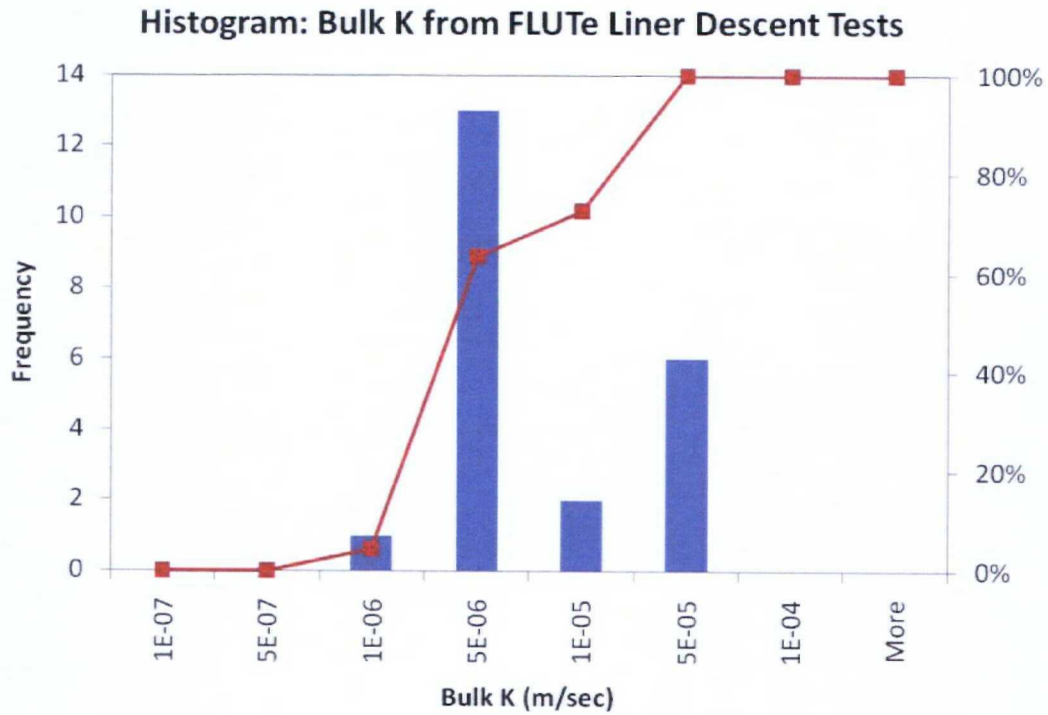


Figure 2. Histograms of (a) matrix porosity, (b) bulk density and (c) total organic carbon (TOC) based on measurements by Golder Associates on 41 samples from core holes MW-14, MW-16 and MW-20.

(a)



(b)

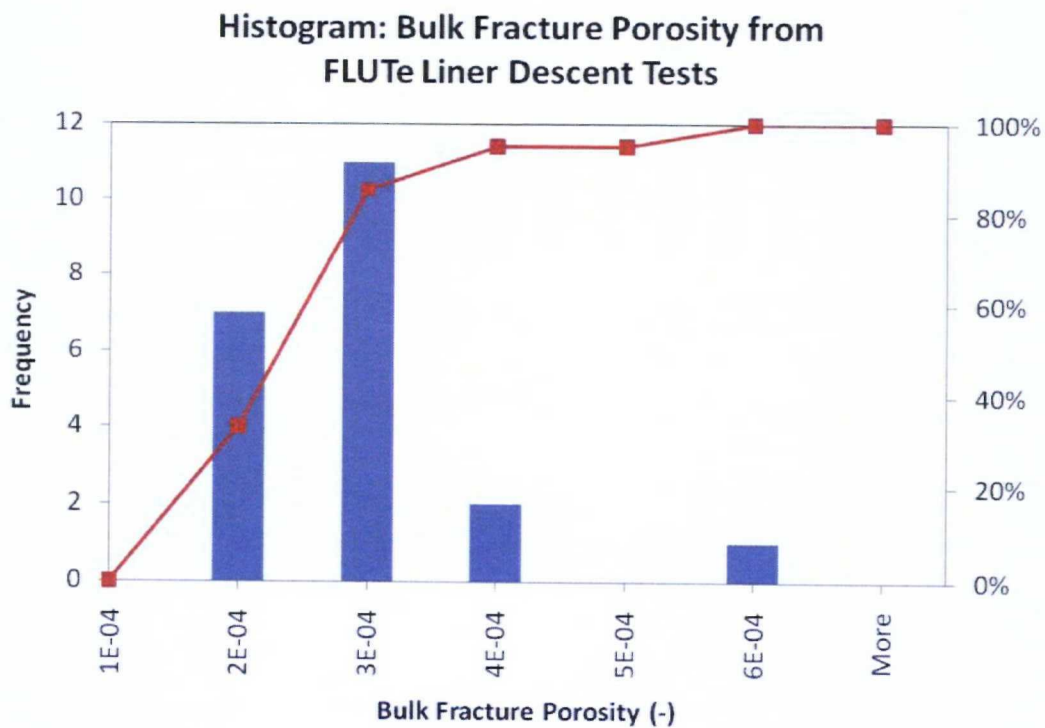


Figure 3. Histograms of (a) overall bulk hydraulic conductivity and (b) overall bulk fracture porosity estimated from the FLUTE liner descent tests conducted in 22 coreholes at the site.

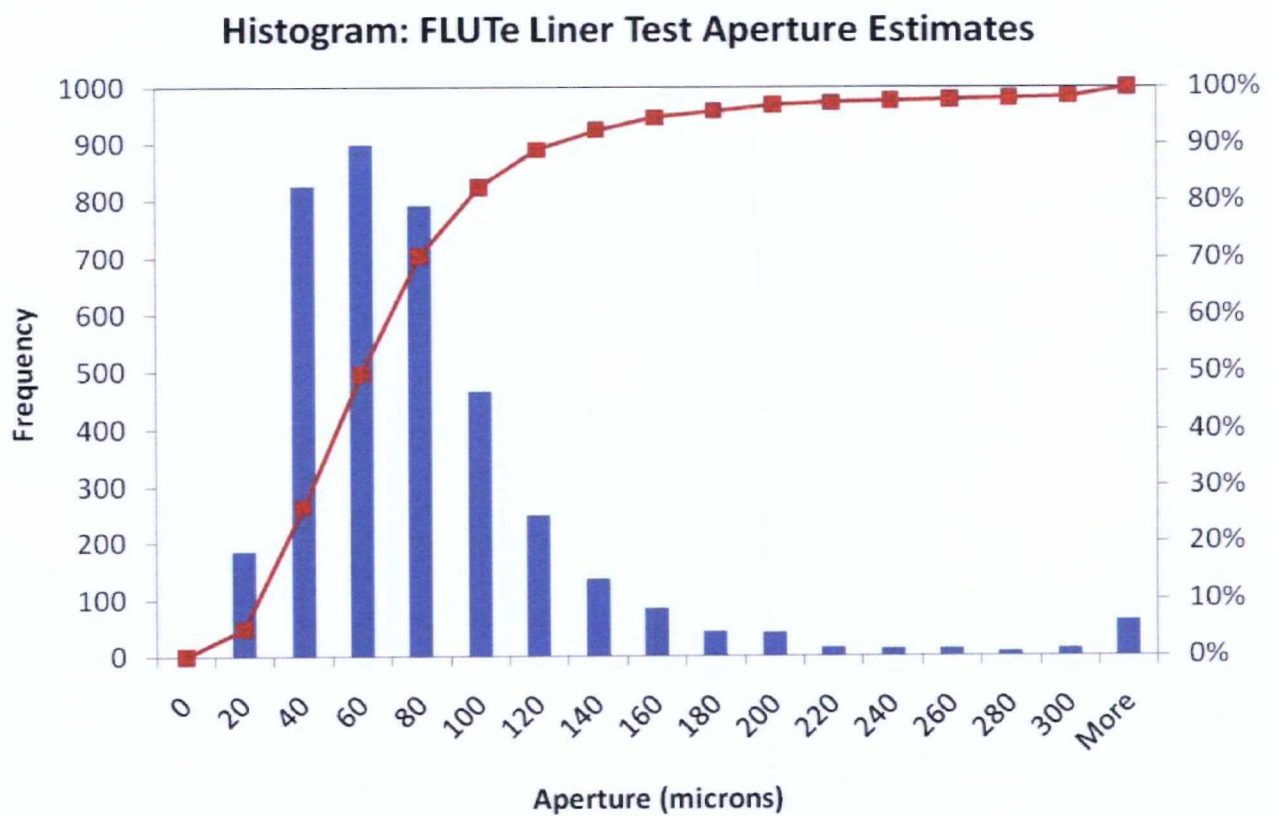


Figure 4. Histogram of individual fracture apertures estimated based on the FLUTe liner descent tests conducted in 22 coreholes at the site.

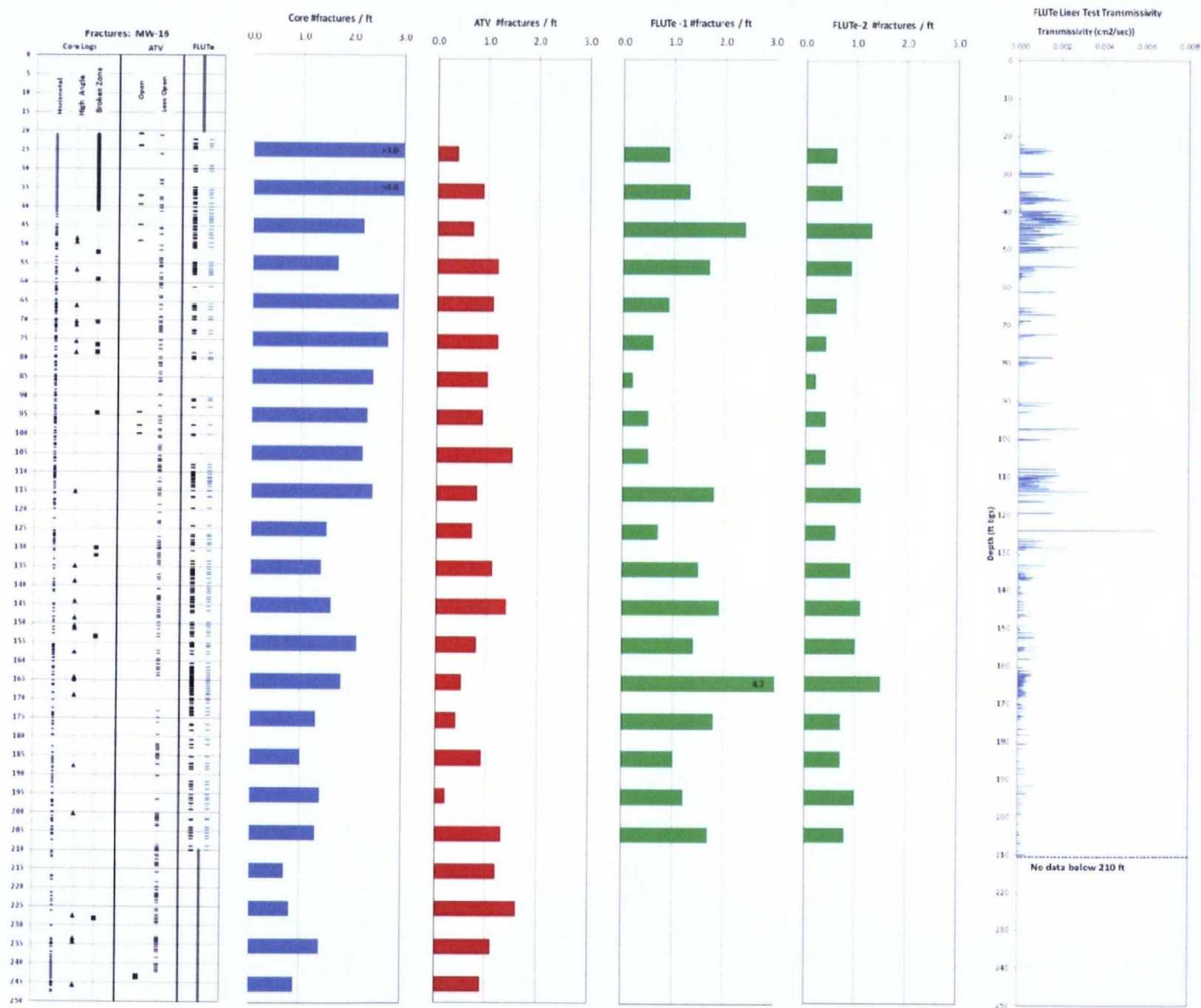
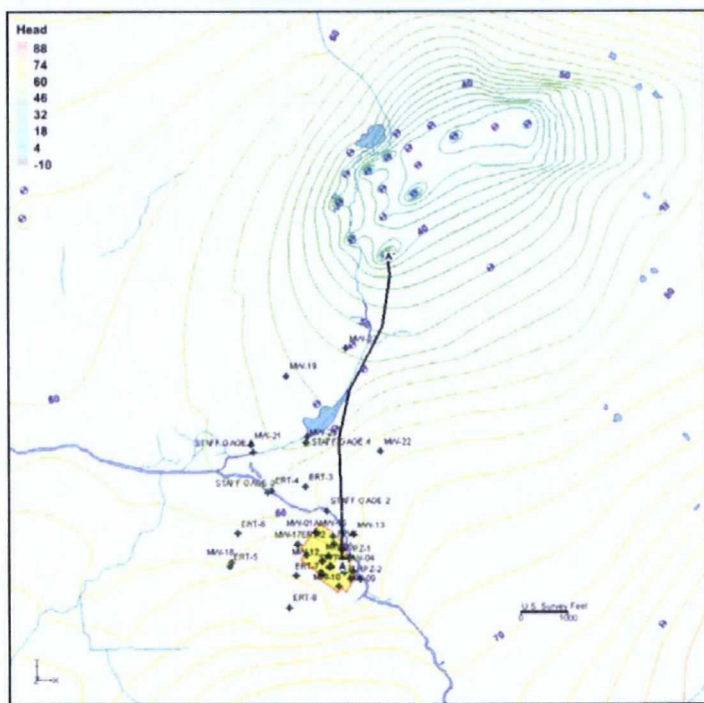
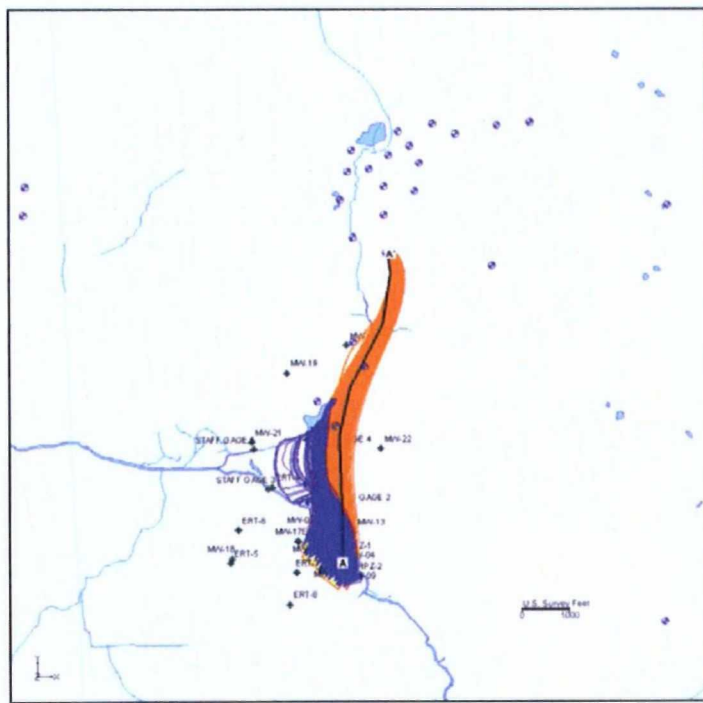


Figure 5. Example of fractures observed at MW-16 in cores and via acoustic televiewer and inferred from the FLUTE liner tests along with estimated fracture frequency (over 10 ft intervals) and transmissivity profile from the FLUTE liner testing.

(a)



(b)



(c)

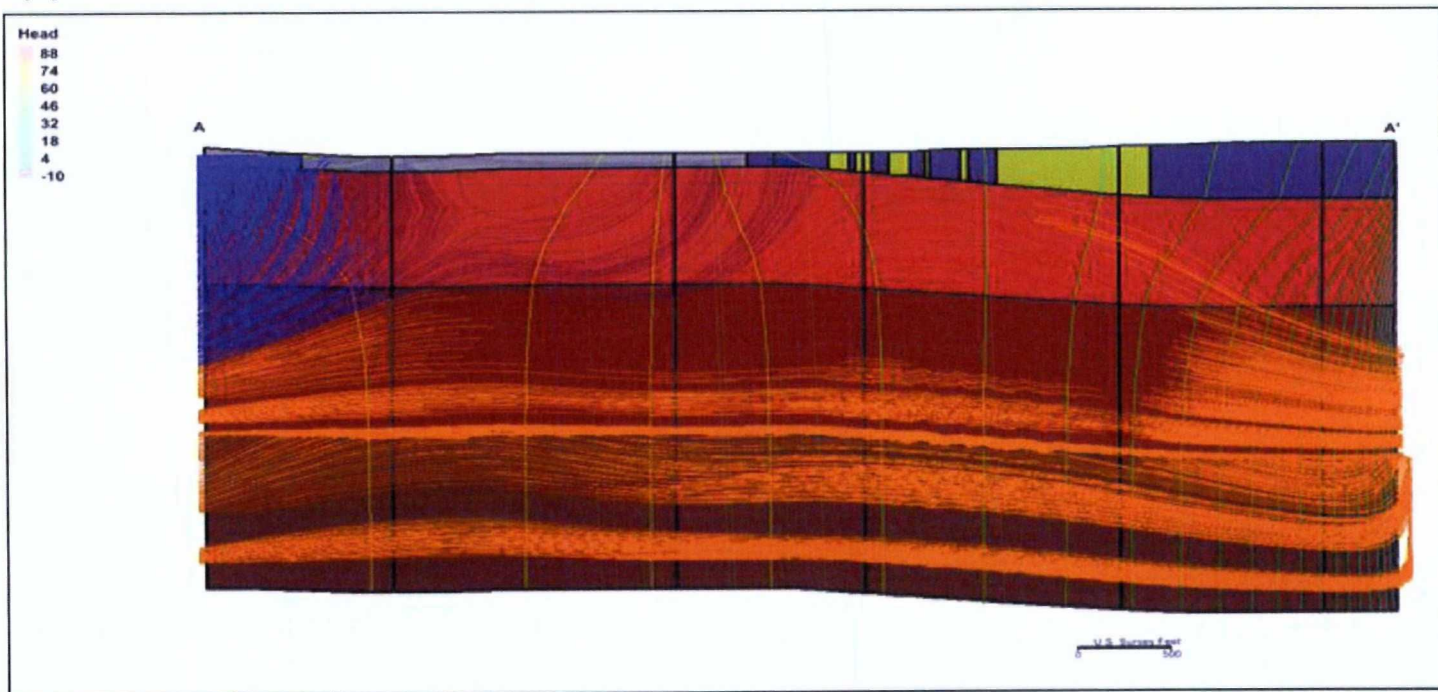


Figure 6. Selected results from the MODFLOW EPM simulations showing: (a) simulated potentiometric surface and position of the cross-section along the plume flowpath, and flow pathlines for particles released from the source area in (b) plan view and (c) along the cross-section.

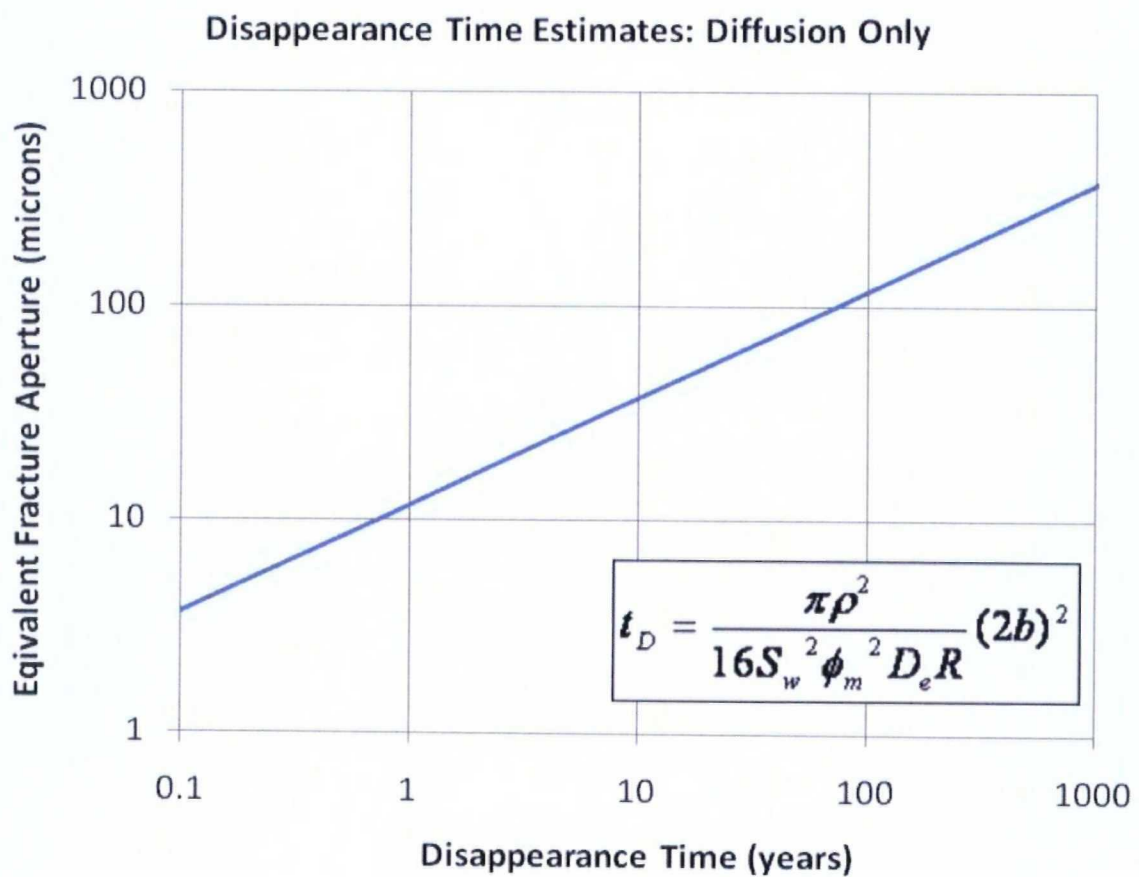
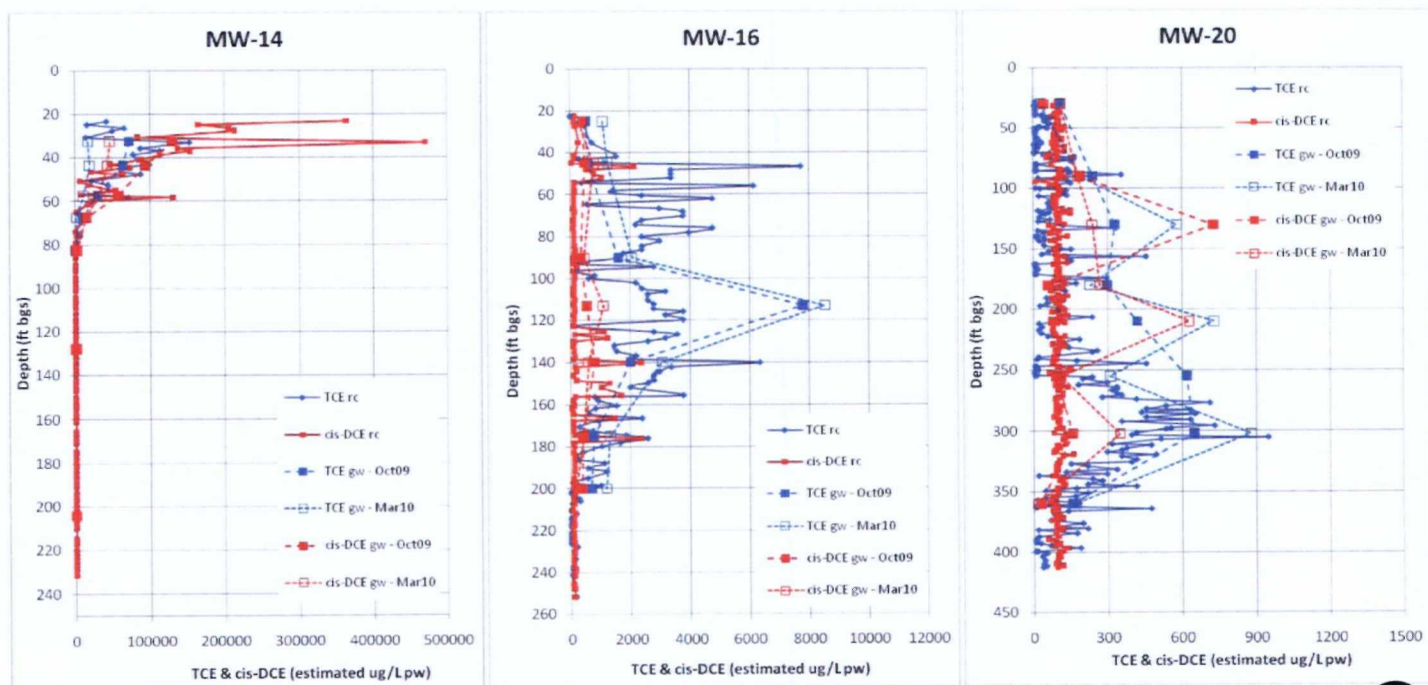


Figure 7. Plot showing equivalent fracture aperture versus DNAPL disappearance time based on diffusion only applying average site matrix parameters (based on methodology in Parker et al., 1994).

(a)



(b)

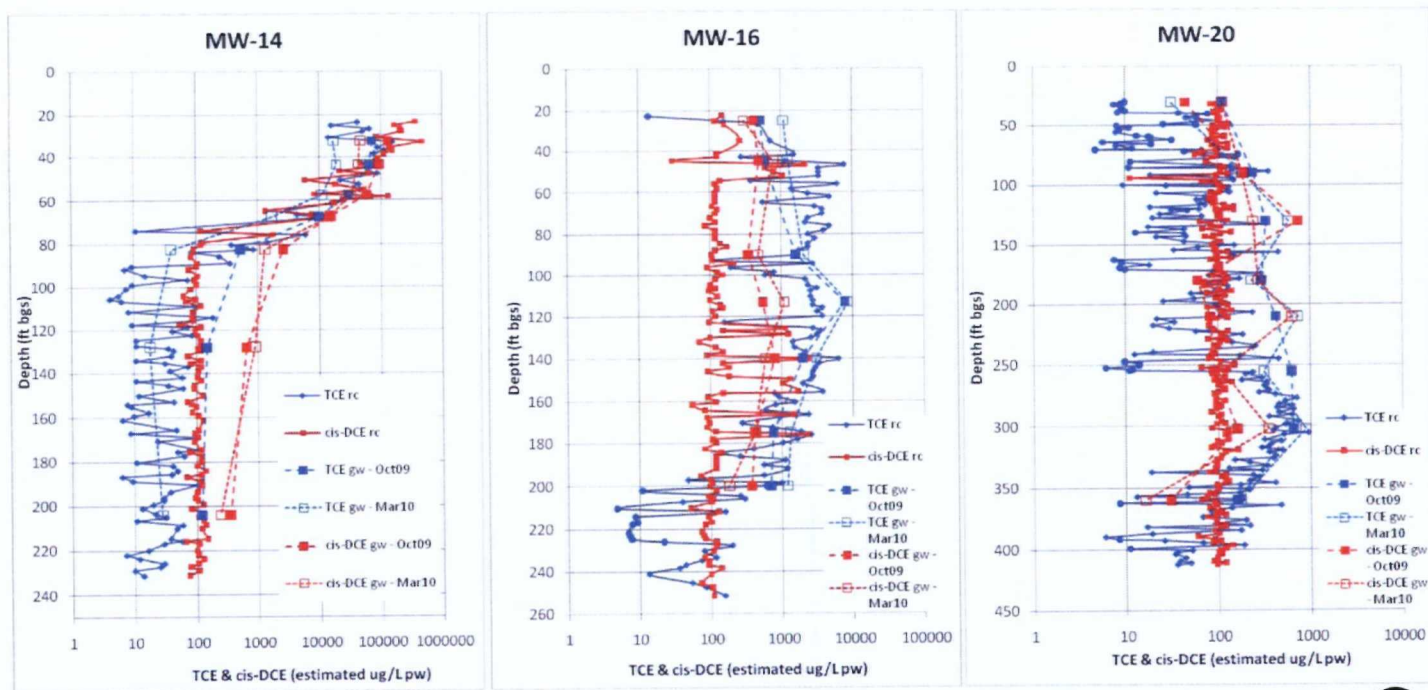
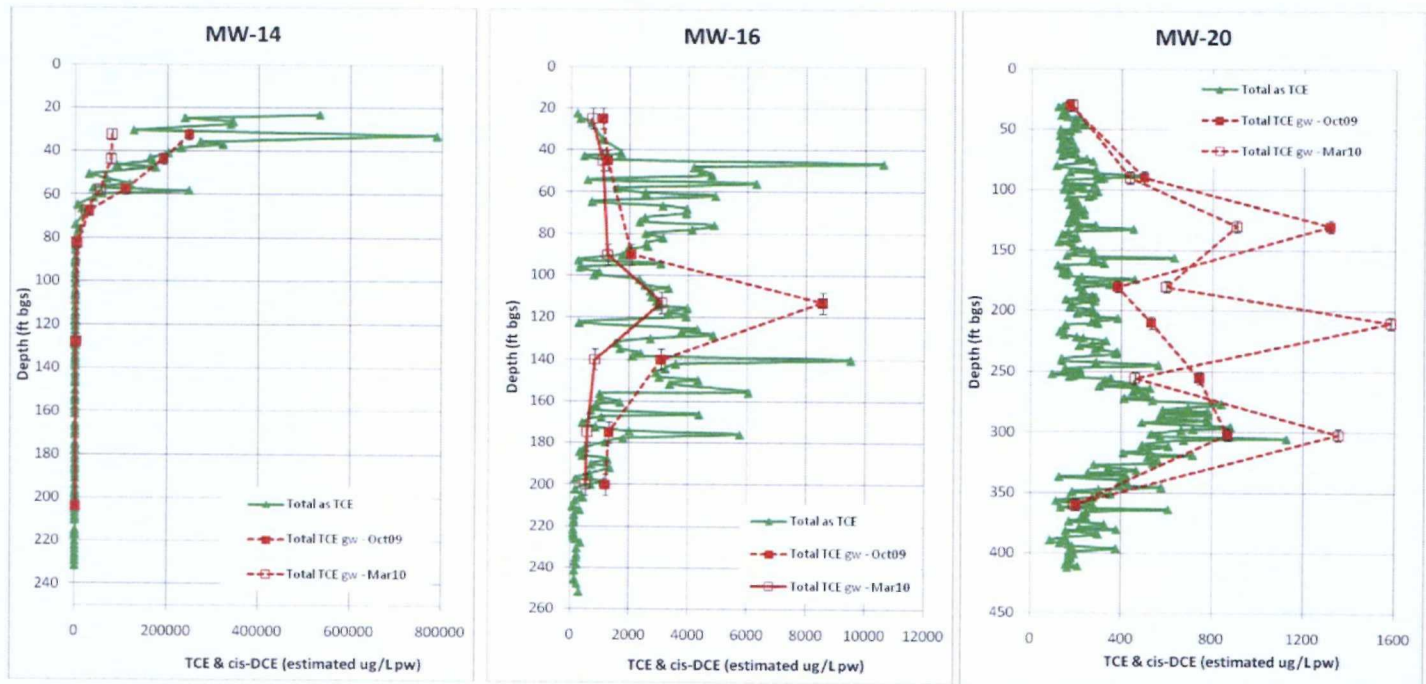


Figure 8. Rock core VOC profiles along the plume flowpath showing estimated TCE and cis-DCE porewater concentrations at MW-14, MW-16 and MW-20 along with groundwater concentrations from two sampling events of the FLUTE multilevel wells installed in these holes, plotted on (a) linear, and (b) logarithmic concentration scales.

(a)



(b)

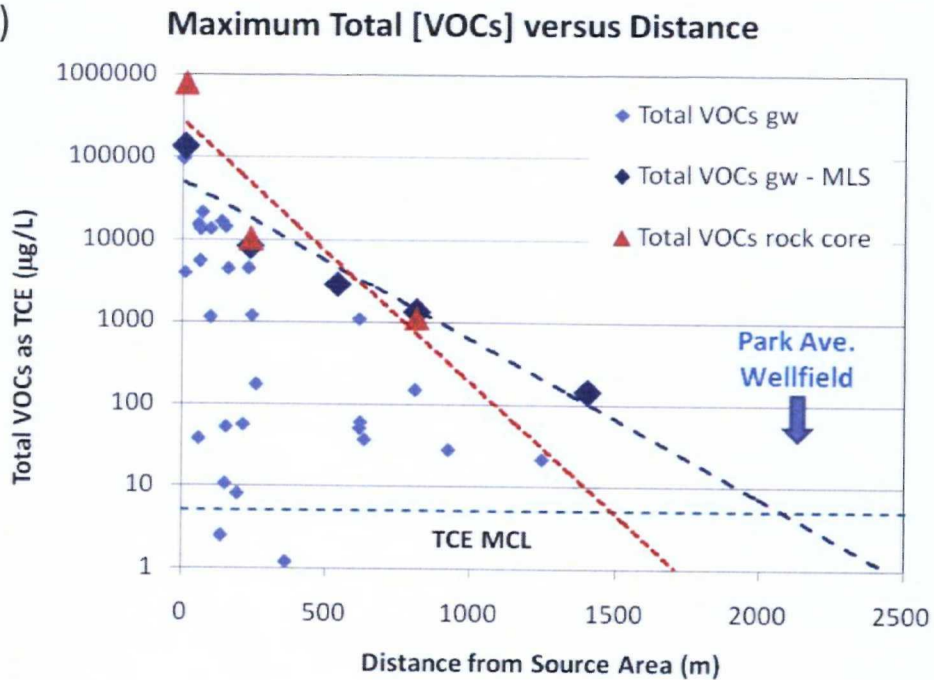


Figure 9. Plots of (a) equivalent TCE concentrations at MW-14, MW-16 and MW-20 from rock core sampling and groundwater sampling of FLUTE multilevel wells installed in these holes, and (b) maximum equivalent TCE versus distance from the site from rock core data and FLUTE multilevel well data along the plume centerline. Data from other monitoring wells and FLUTE multilevel wells are also shown but not used in the interpolations.

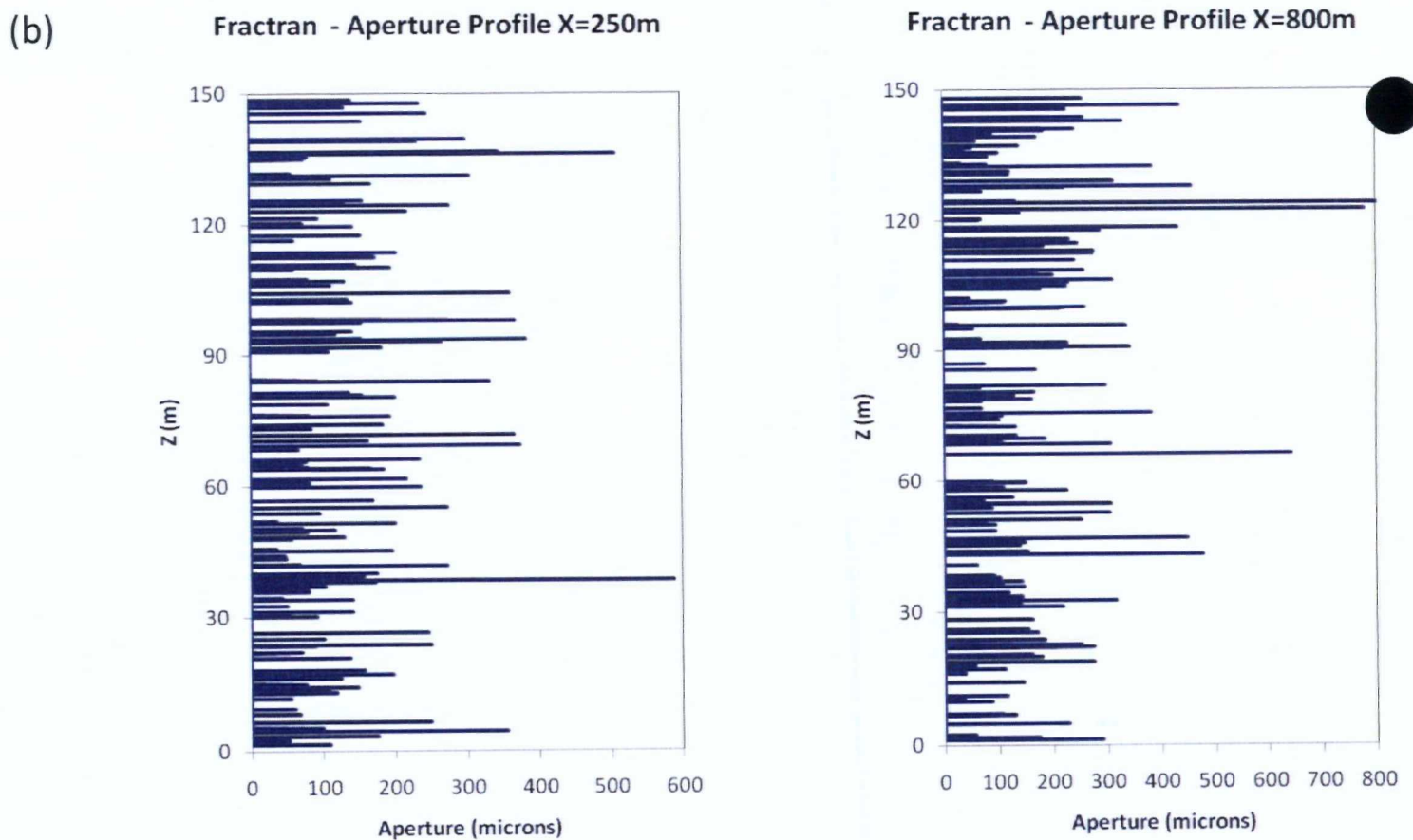
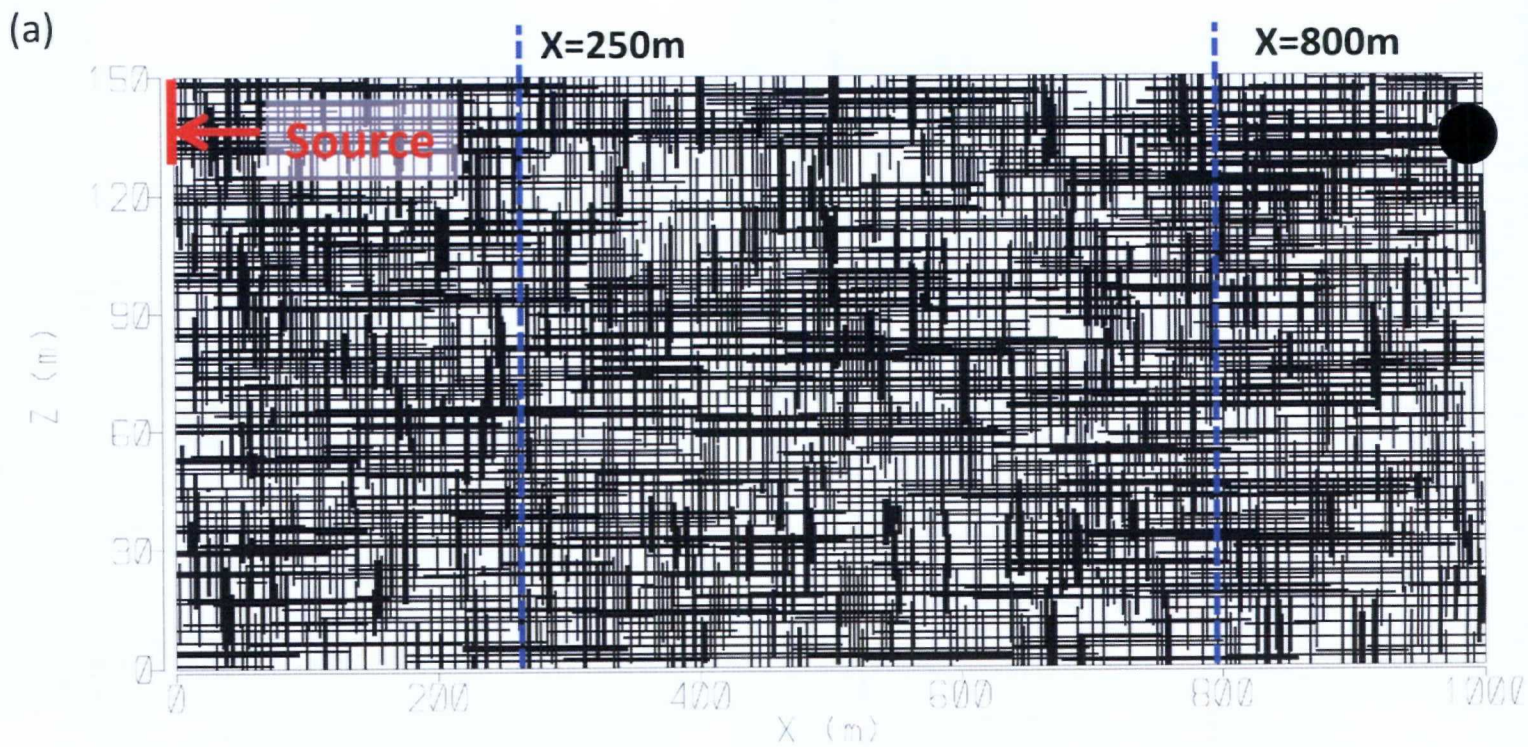


Figure 10. Plots showing (a) FRACTRAN model domain and fracture network, and (b) example profiles showing fracture positions and apertures at X=250 m and 800 m.

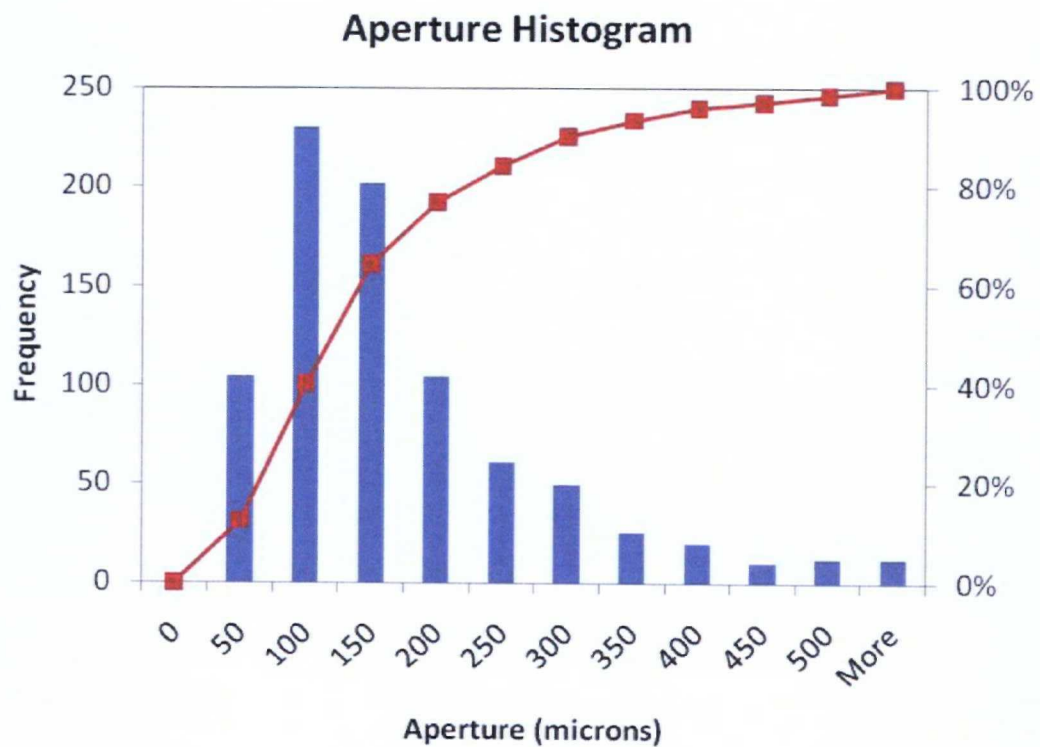


Figure 11. Histogram of horizontal fracture apertures used in the FRACTRAN simulation.

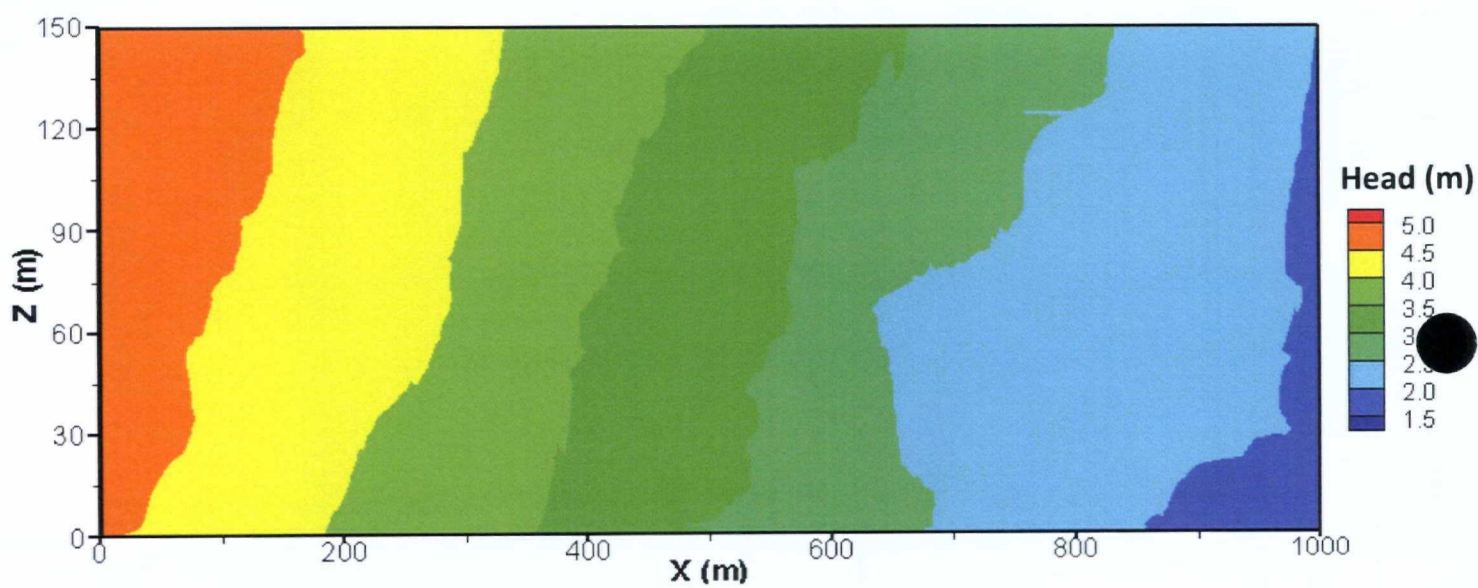


Figure 12. FRACTRAN flow simulation results showing simulated potentiometric surface. Average hydraulic gradients are 0.3% horizontal and 0.3% vertical (downward).

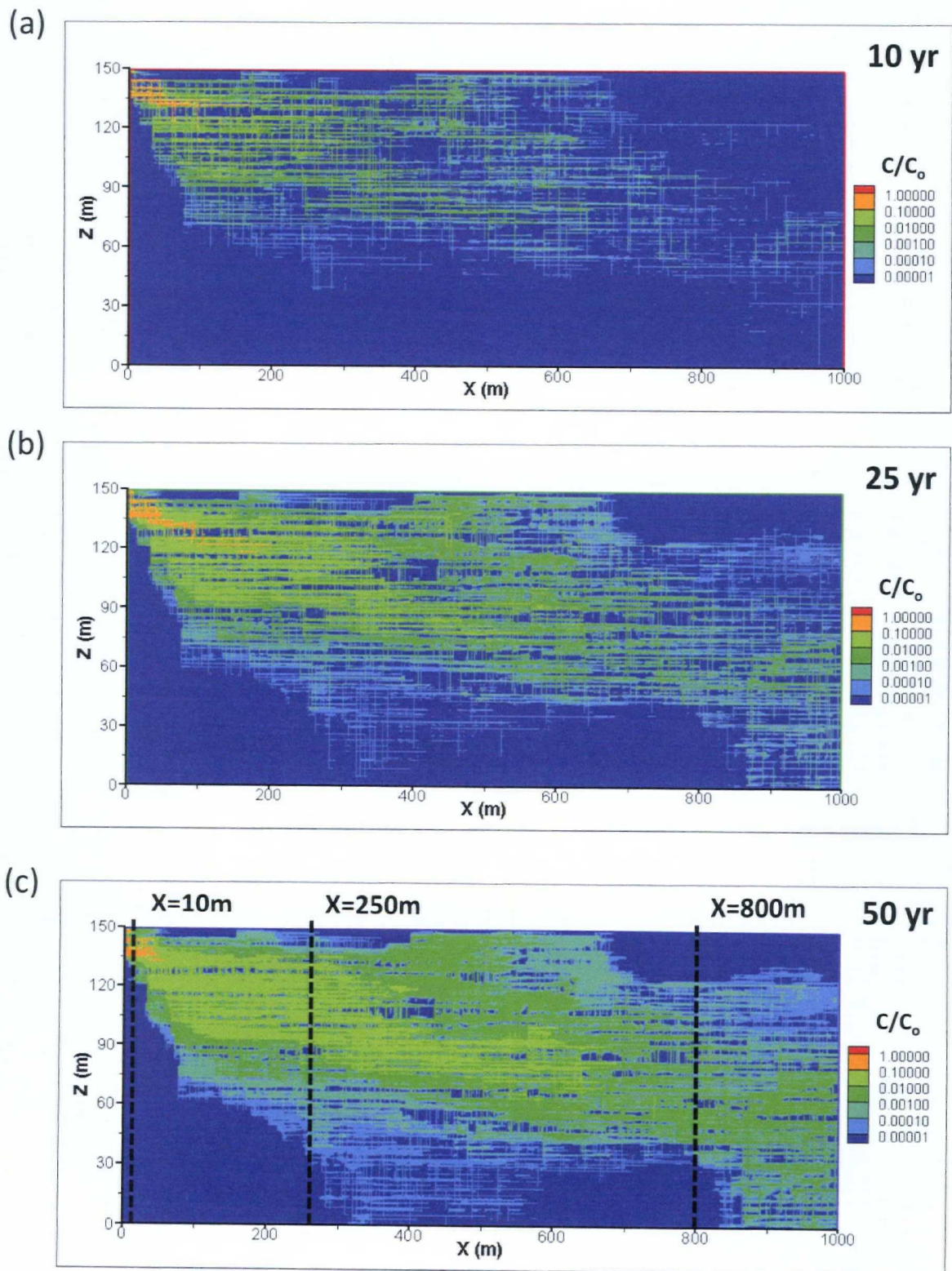
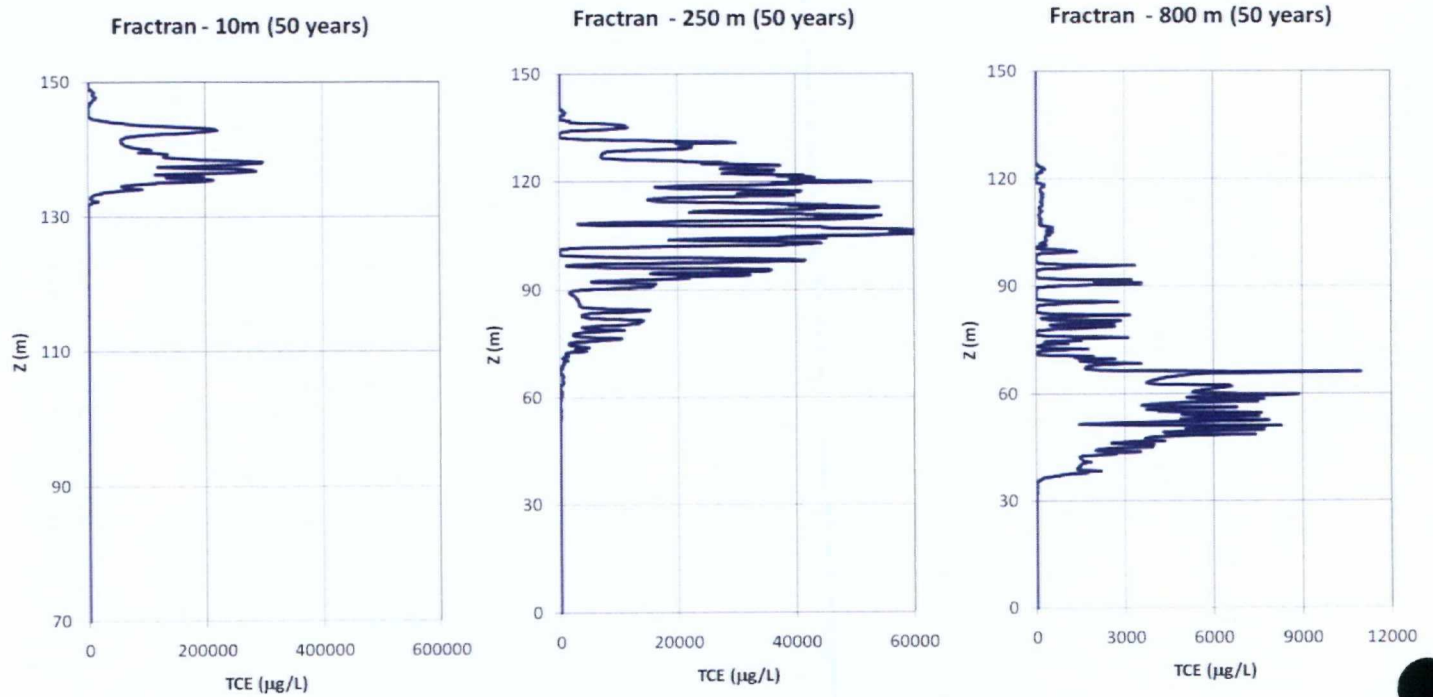


Figure 13. FRACTRAN simulated contaminant plumes at 10, 25 and 50 years plotted as relative concentrations over a 5 order of magnitude range.

(a) FRACTRAN simulated profiles at 50 years



(b) Field rock core profiles

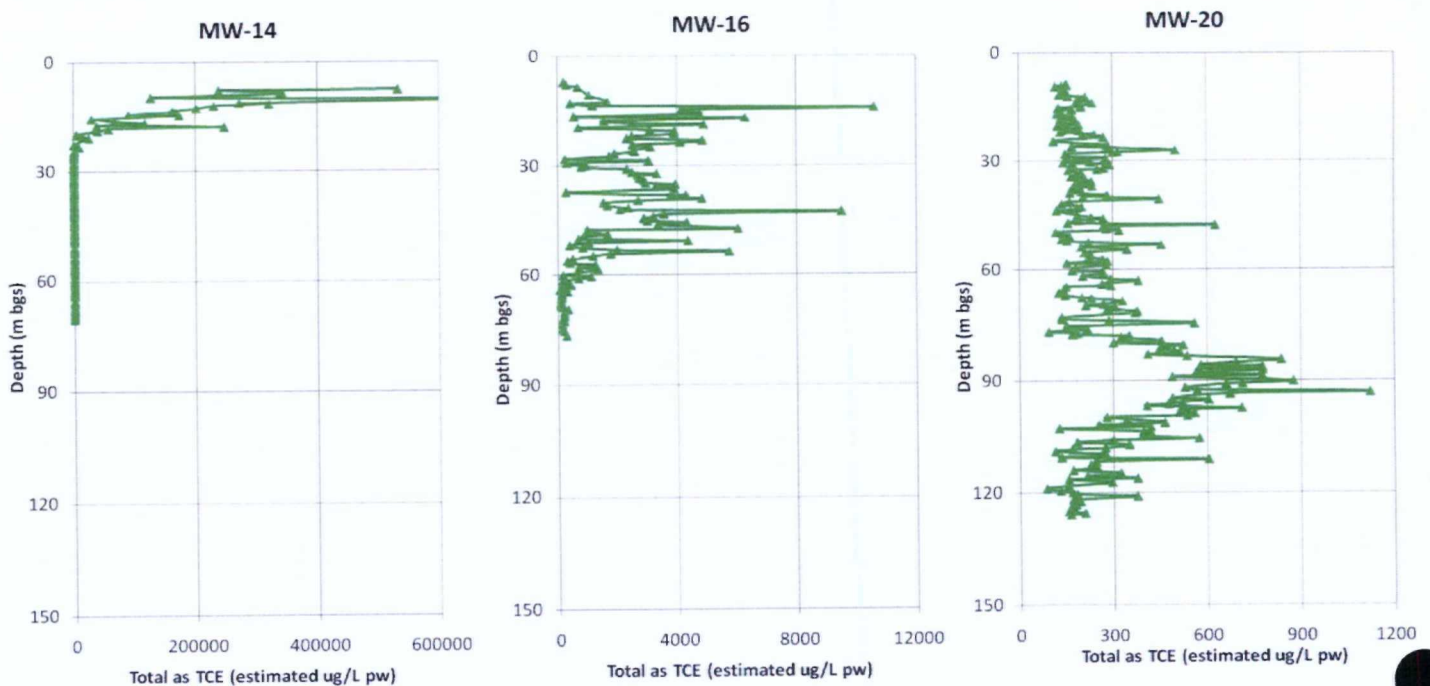


Figure 14. Comparison of (a) FRACTRAN simulated versus (b) field rock core profiles (equivalent porewater TCE concentrations) showing good 'stylistic' comparison. Note the different concentration scales for the MW-16 (5X lower) and MW-20 (10X lower) field profiles compared to FRACTRAN profiles.

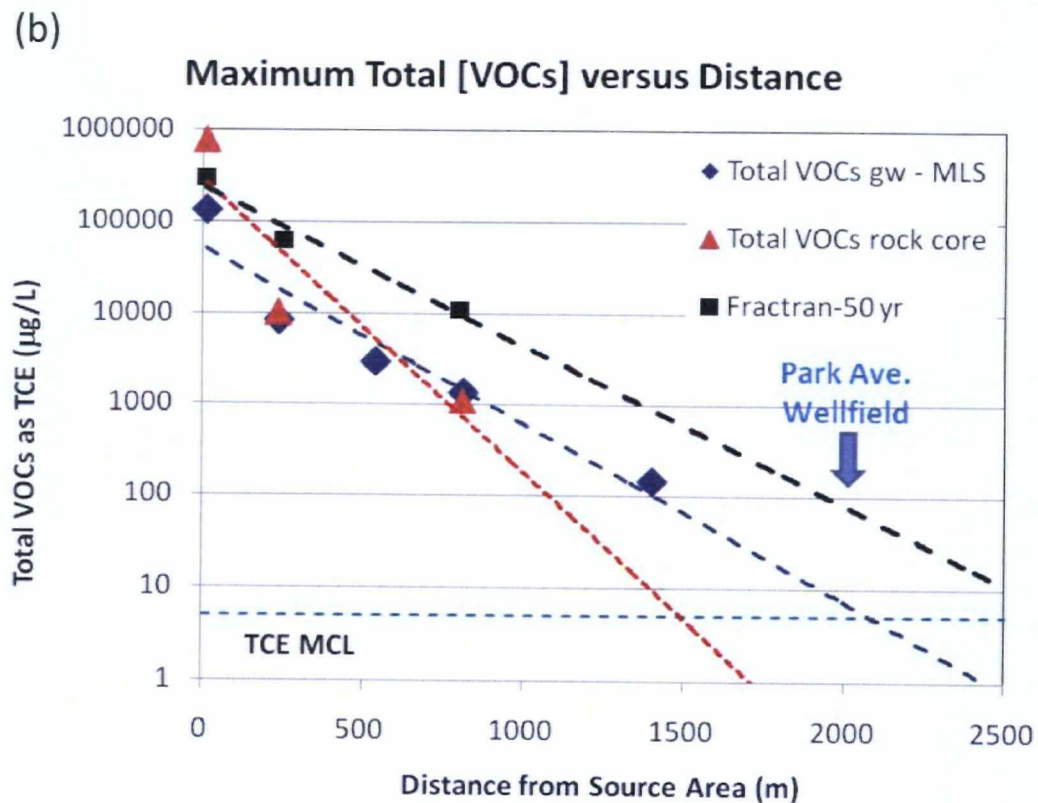
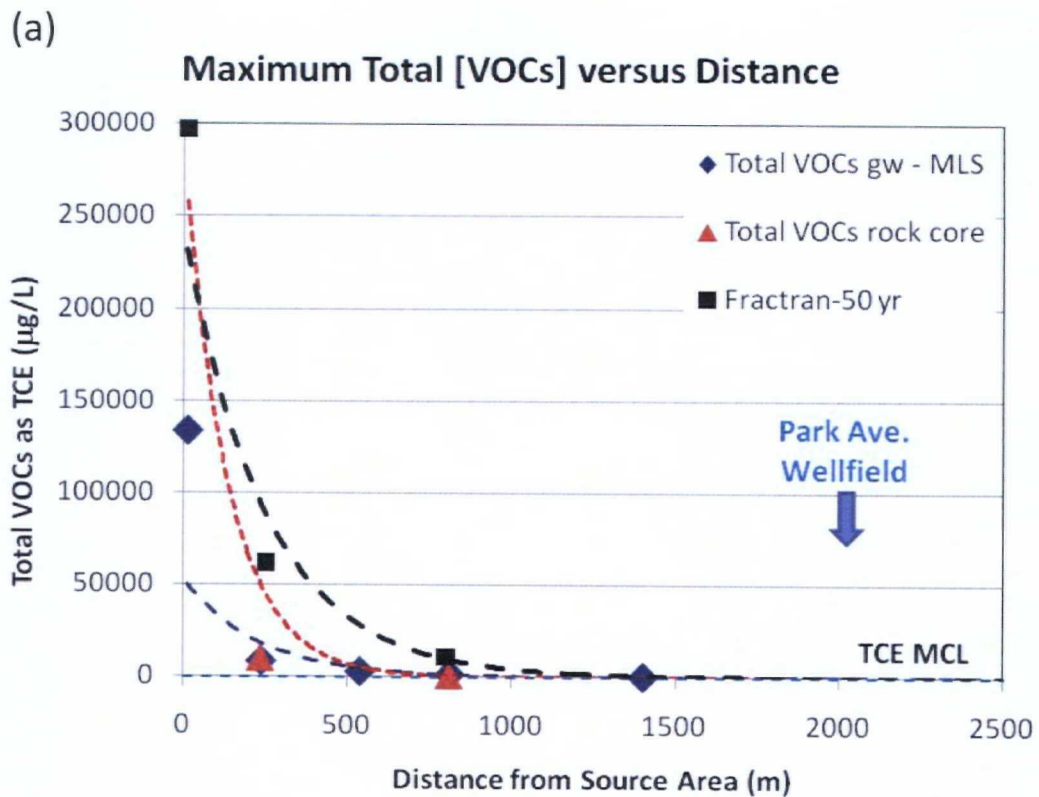


Figure 15. Plots of maximum equivalent TCE with distance from the site on (a) linear and (b) logarithmic concentration scales comparing field data (from rock core VOC sampling and from FLUTE multilevel well sampling along the plume centerline) with the FRACTRAN simulation results.

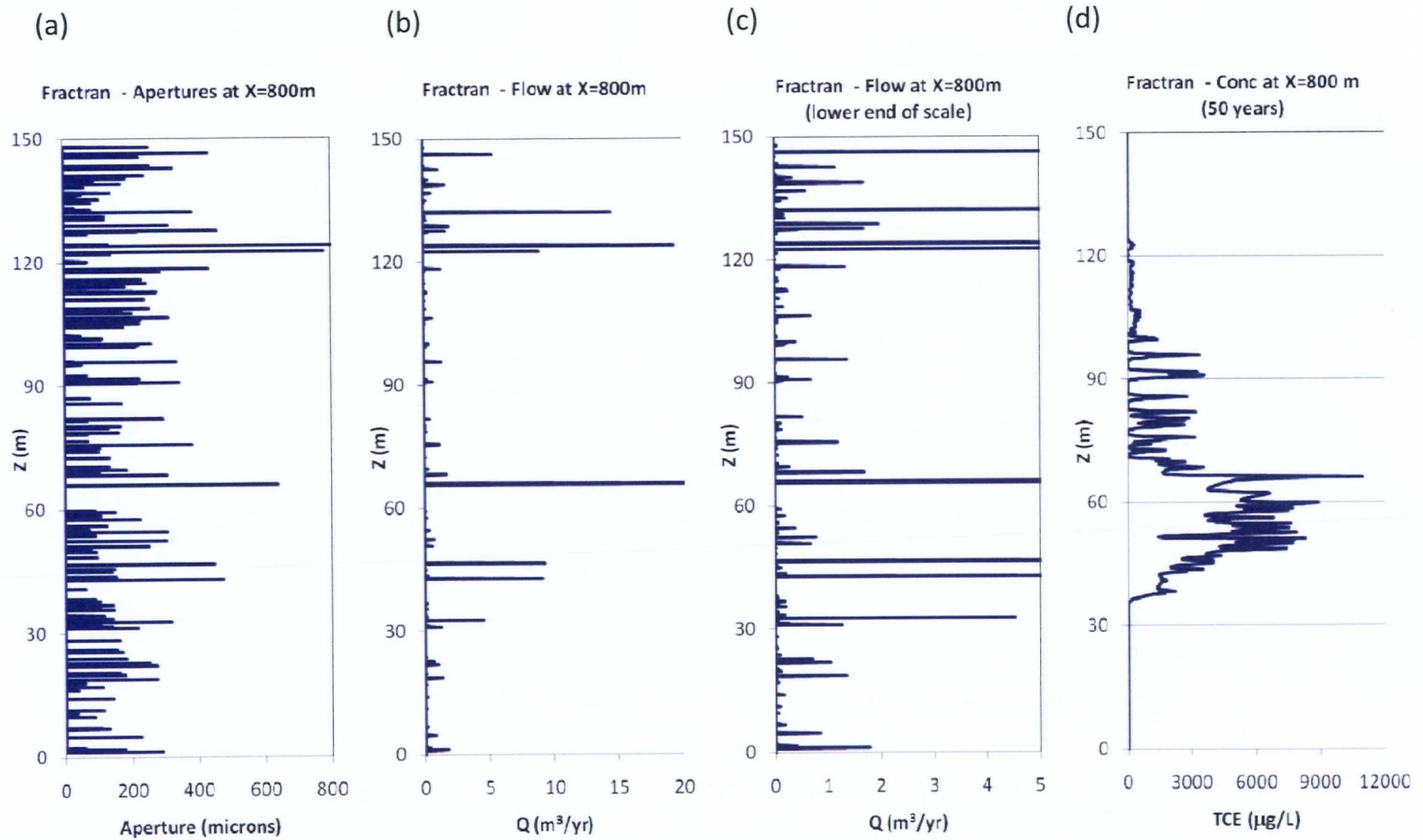
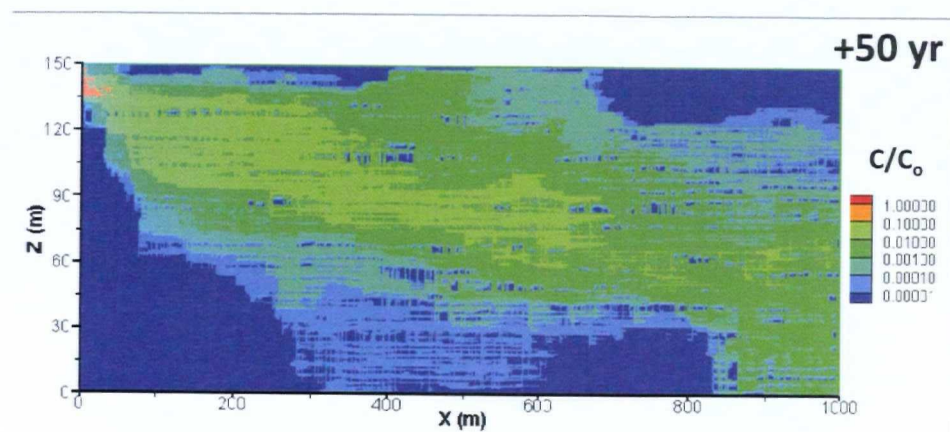
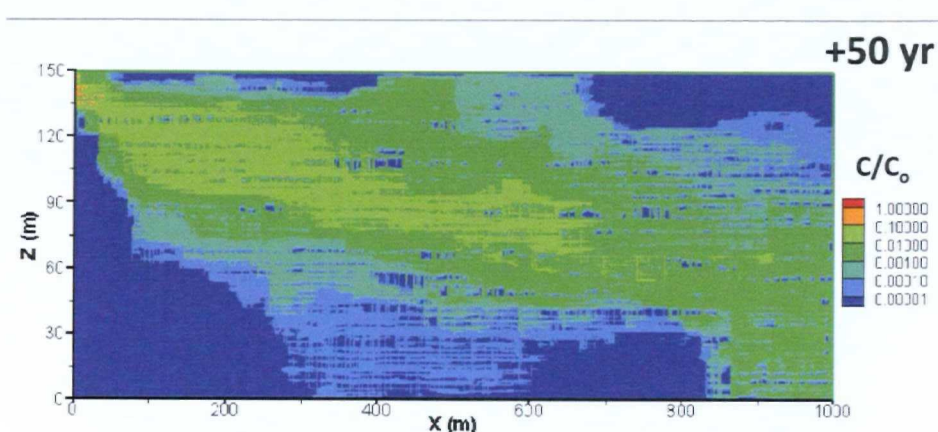


Figure 16. Example of FRACTRAN results at X=800 m showing profiles of (a) fracture positions and apertures, (b) groundwater flow rates, (c) groundwater flow rates on an expanded scale to better show the lower end, and (d) simulated contaminant concentrations at 50 years.

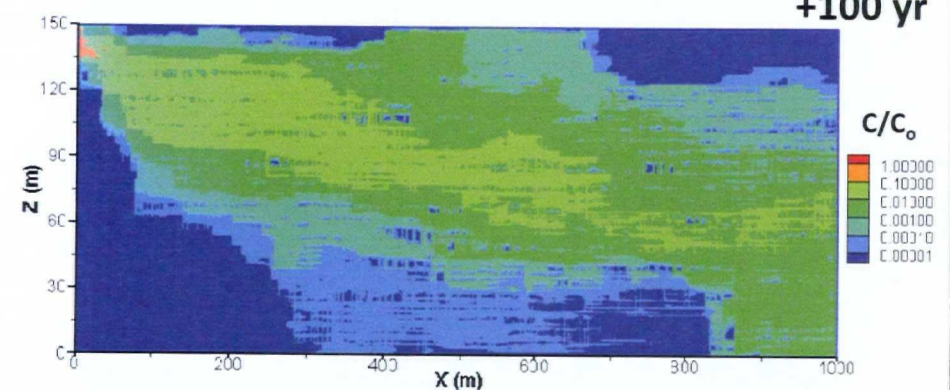
(a)



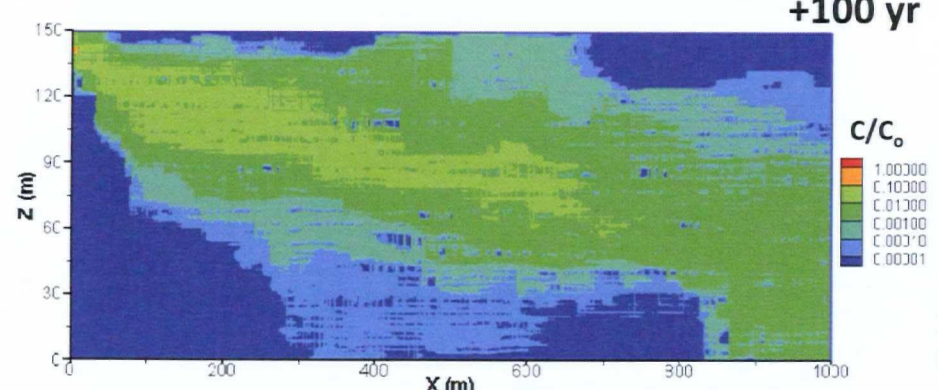
(b)



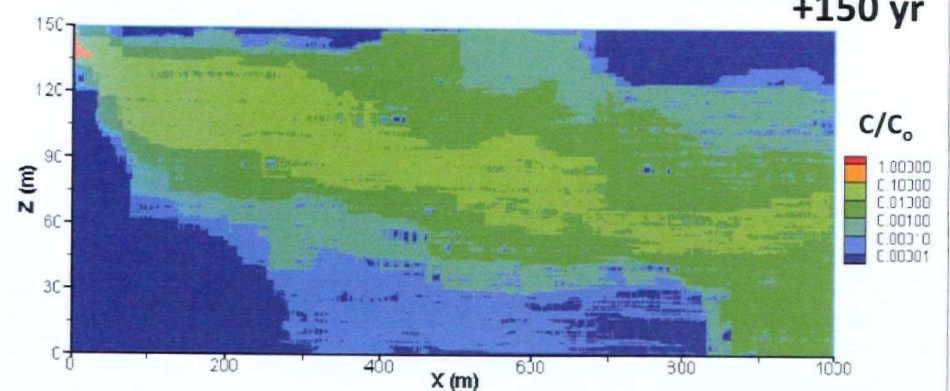
+100 yr



+100 yr



+150 yr



+150 yr

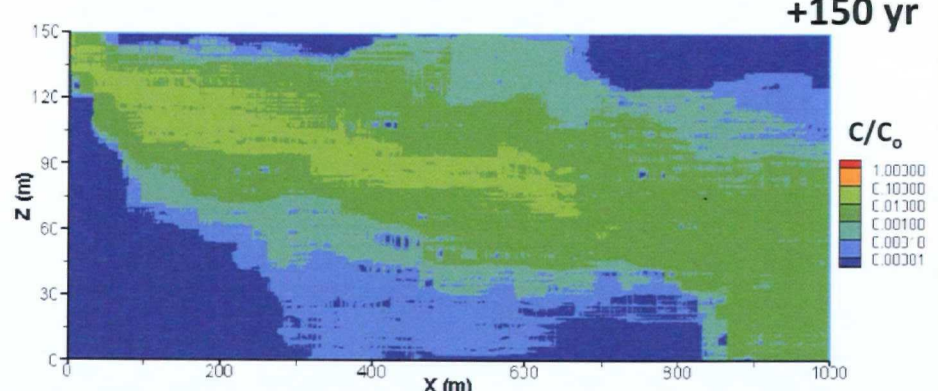


Figure 17. FRACTRAN simulated contaminant plumes at 50, 100 and 150 years from present time for two scenarios of future source inputs: (a) continued input at 10% of solubility, and (b) with complete termination of source input.

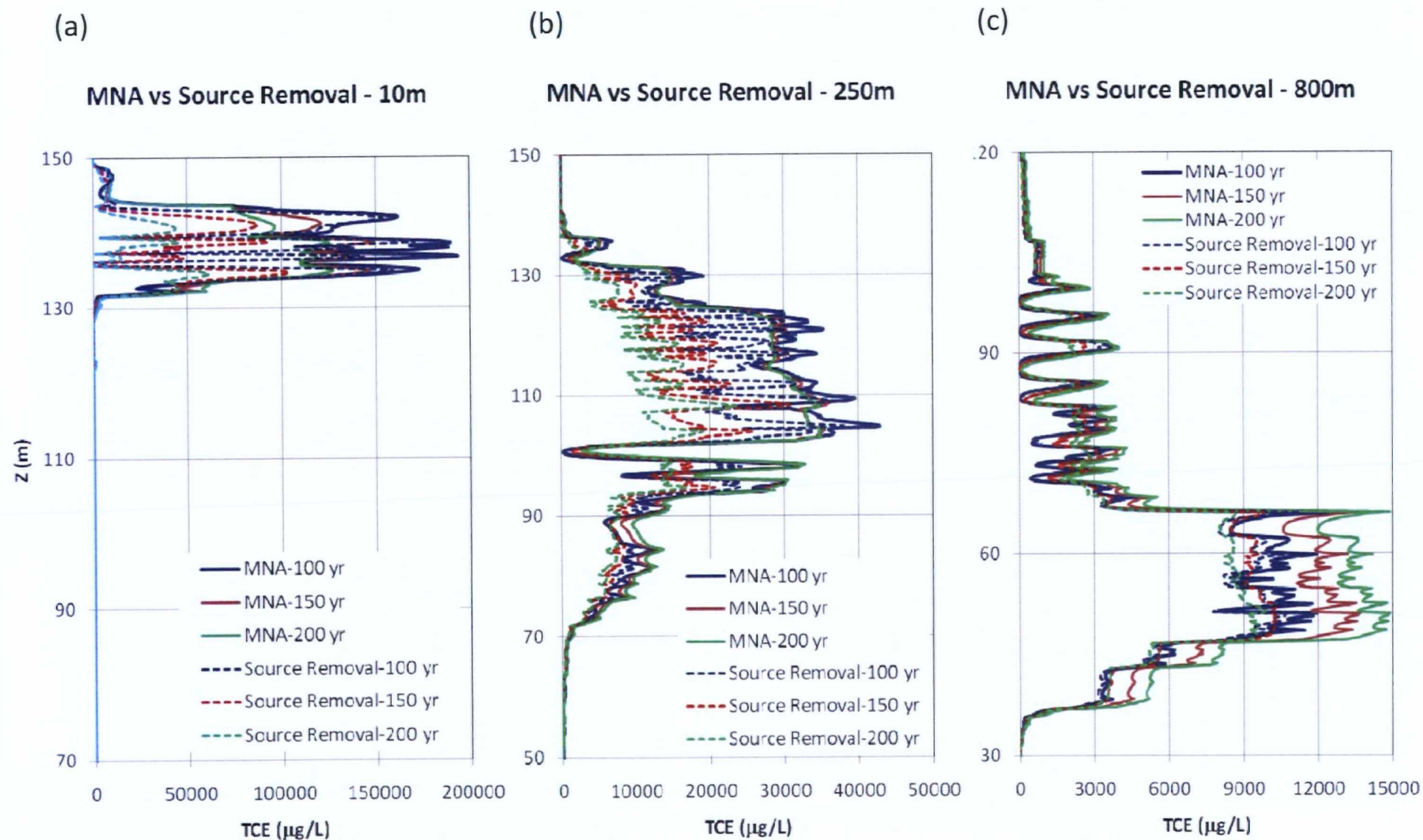


Figure 18. Comparison of FRACTRAN simulated concentration profiles at (a) $X=10$ m, (b) $X=250$ m and (c) $X=800$ m for the two scenarios of future source inputs: (a) continued input at 10% of source strength, and (b) with complete termination of source input.

TABLES

Table 1: Results of physical property analyses on core samples.

Sample ID	Location	Top Depth (ft bgs)	Bottom Depth (ft bgs)	Lithology	Porosity (-)	Water Content (%)	Wet Bulk Density (g/cm ³)	Dry Bulk Density (g/cm ³)	Specific Gravity (-)	Average TOC (%)
CDEMDMW16043.50PHY	MW16	41	44	Mudstone	0.12	2.2	2.57	2.47	2.81	0.0025
CDEMDMW16063.00PHY	MW16	59	64	Mudstone	0.13	4.9	2.52	2.40	2.75	0.0025
CDEMDMW16083.00PHY	MW16	79	84	Mudstone	0.11	3.9	2.56	2.46	2.78	0.0115
CDEMDMW16103.10PHY	MW16	99	104	Mudstone	0.09	3.2	2.56	2.48	2.72	0.0166
CDEMDMW16129.30PHY	MW16	129	134	Mudstone	0.06	2.2	2.62	2.57	2.74	0.0025
CDEMDMW16143.00PHY	MW16	139	144	Mudstone	0.09	3.3	2.63	2.54	2.80	0.0025
CDEMDMW16163.30PHY	MW16	159	164	Mudstone	0.08	2.3	2.61	2.56	2.77	0.0025
CDEMDMW16183.40PHY	MW16	179	184	Mudstone	0.06	1.7	2.66	2.61	2.77	0.0025
CDEMDMW16202.50PHY	MW16	199	204	Mudstone	0.12	4.6	2.59	2.48	2.82	0.0171
CDEMDMW16220.00PHY	MW16	219	224	Mudstone	0.07	2.2	2.67	2.61	2.80	0.2000
CDEMDMW16241.10PHY	MW16	239	244	Mudstone	0.06	2.2	2.62	2.56	2.73	0.0025
CDEMDMW20036.80PHY	MW20	33	38	Mudstone	0.17	7.2	2.44	2.27	2.74	0.0025
CDEMDMW20060.90PHY	MW20	58	63	Mudstone	0.17	6.3	2.51	2.36	2.83	0.0025
CDEMDMW20085.40PHY	MW20	83	88	Mudstone	0.11	3.9	2.61	2.51	2.82	0.0025
CDEMDMW20104.70PHY	MW20	103	108	Mudstone	0.13	5.0	2.60	2.48	2.85	0.0025
CDEMDMW20125.35PHY	MW20	123	128	Mudstone	0.09	3.8	2.62	2.52	2.79	0.0028
CDEMDMW20143.50PHY	MW20	143	148	Mudstone	0.12	4.6	2.60	2.48	2.82	0.0025
CDEMDMW20165.40PHY	MW20	163	168	Mudstone	0.10	3.5	2.64	2.55	2.83	0.0241
CDEMDMW20186.60PHY	MW20	183	188	Mudstone	0.09	3.9	2.59	2.49	2.75	0.0025
CDEMDMW20204.40PHY	MW20	203	208	Mudstone	0.08	3.3	2.63	2.55	2.78	0.0287
CDEMDMW20225.60PHY	MW20	223	228	Mudstone	0.10	3.4	2.61	2.52	2.81	0.0025
CDEMDMW20246.20PHY	MW20	243	248	Mudstone	0.09	2.9	2.63	2.56	2.80	0.0157
CDEMDMW20267.70PHY	MW20	263	268	Mudstone	0.11	3.9	2.55	2.45	2.76	0.0028
CDEMDMW20287.70PHY	MW20	283	288	Mudstone	0.08	2.8	2.63	2.55	2.78	0.0028
CDEMDMW20308.40PHY	MW20	308	313	Mudstone	0.08	2.8	2.64	2.57	2.79	0.0129
CDEMDMW20330.00PHY	MW20	328	333	Mudstone	0.07	2.5	2.64	2.58	2.77	0.0025
CDEMDMW20352.70PHY	MW20	348	353	Mudstone	0.12	3.7	2.58	2.48	2.81	
CDEMDMW20368.70PHY	MW20	368	373	Mudstone	0.10	3.0	2.64	2.56	2.83	0.0199
CDEMDMW20388.40PHY	MW20	388	393	Mudstone	0.08	2.8	2.62	2.55	2.77	0.0122
CDEMDMW20408.40PHY	MW20	408	413	Mudstone	0.08	2.8	2.63	2.56	2.78	0.0025
CDEMDMW14027.20PHY	MW14	24	29	Mudstone	0.16	7.0	2.52	2.36	2.82	0.0028
CDEMDMW14049.30PHY	MW14	49	54	Mudstone	0.13	5.1	2.55	2.42	2.78	0.0025
CDEMDMW14075.90PHY	MW14	73	78	Mudstone	0.09	2.9	2.62	2.55	2.80	0.0332
CDEMDMW14093.40PHY	MW14	93	98	Mudstone	0.09	3.4	2.62	2.54	2.80	0.0247
CDEMDMW14110.00PHY	MW14	108	113	Mudstone	0.08	2.9	2.64	2.56	2.78	0.0227
CDEMDMW14131.00PHY	MW14	128	133	Mudstone	0.07	1.9	2.67	2.62	2.82	0.0025
CDEMDMW14151.10PHY	MW14	148	153	Mudstone	0.11	3.9	2.65	2.55	2.86	0.0146
CDEMDMW14171.80PHY	MW14	168	173	Mudstone	0.08	2.8	2.66	2.58	2.81	0.0148
CDEMDMW14192.00PHY	MW14	188	193	Mudstone	0.08	2.1	2.62	2.56	2.78	0.0177
CDEMDMW14211.40PHY	MW14	208	213	Mudstone	0.09	2.7	2.60	2.54	2.80	0.0164
CDEMDMW14232.50PHY	MW14	213	228	Mudstone	0.12	4.1	2.54	2.44	2.78	0.0153
				Minimum	0.06	1.7	2.44	2.27	2.72	0.0025
				Maximum	0.17	7.2	2.67	2.62	2.86	0.2000
				Average	0.10	3.50	2.60	2.51	2.79	0.0144
				Average*	0.10	3.5	2.60	2.51	2.79	0.0096

* excluding apparent TOC outlier at MW-16 (219-224 ft)

Table 2: Summary of estimated aperture ranges and bulk hydraulic conductivity and fracture porosity from FLUTe liner descent test:

Bedrock Well Number	Borehole Length ¹ (feet)	Number of Fractures ²	Number of Fractures per foot of Borehole	Aperture Data ³				Bulk Hydraulic Conductivity (m/sec)	Bulk Fracture Porosity ⁴ (-)
				Minimum (microns)	Maximum (microns)	Geometric Mean (microns)	Standard Deviation		
MW-13	215	241	1.12	4	504	102	59	4.2E-06	2.4E-04
MW-14S	48	18	0.38	39	434	93	85	3.3E-06	1.3E-04
MW-14D	189	212	1.12	15	421	54	40	1.8E-06	2.3E-04
MW-15S	78	140	1.79	6	477	48	60	5.9E-06	3.7E-04
MW-15D	123	234	1.90	3	318	117	36	1.2E-06	3.2E-04
MW-16	194	268	1.38	8	122	52	23	6.5E-07	2.3E-04
MW-17	220	164	0.75	2	1269	35	109	2.2E-05	1.3E-04
MW-18	220	262	1.19	11	470	64	45	3.1E-06	2.8E-04
MW-19	474	224	0.47	9	401	75	50	1.7E-06	1.3E-04
MW-20	351	221	0.63	4	642	169	58	2.7E-06	1.4E-04
MW-21	481	311	0.65	6	509	69	55	2.8E-06	1.7E-04
MW-22	245	211	0.86	15	417	67	43	2.0E-06	2.1E-04
MW-23	420	585	1.39	5	277	50	33	1.4E-06	2.7E-04
FPW	262	267	1.02	9	456	76	55	4.1E-06	2.9E-04
ERT-1	120	75	0.63	11	962	84	164	3.3E-05	2.7E-04
ERT-2	127	35	0.28	11	680	88	141	9.0E-06	1.2E-04
ERT-3	131	63	0.48	37	885	135	139	2.1E-05	2.6E-04
ERT-4	67	71	1.06	12	628	117	117	1.4E-05	5.2E-04
ERT-5	123	83	0.67	6	447	57	80	4.5E-06	1.7E-04
ERT-6	76	33	0.43	34	694	133	148	1.4E-05	2.4E-04
ERT-7	128	123	0.96	11	455	62	60	3.9E-06	2.4E-04
ERT-8	112	61	0.54	17	565	71	135	1.4E-05	
Average			0.90	13	547	83	79	7.7E-06	2.4E-04
Min			0.28	2	122	35	23	6.5E-07	1.2E-04
Max			1.90	39	1269	169	164	3.3E-05	5.2E-04

1 - Length of the borehole tested during the drop liner test

2 - Number of fractures as interpreted by a change in transmissivity during the drop liner test

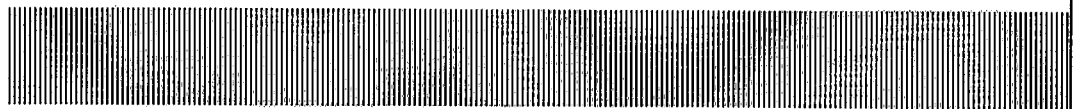
3 - Apertures estimated using the cubic law assuming one fracture represented by sequential T values in the FLUTe liner test dataset

4 - Bulk fracture porosity estimated by summing all apertures along the borehole and dividing by the borehole test length

United States Army Corps of Engineers, Kansas City
Draft Feasibility Study Report
Operable Unit 3: Groundwater
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Appendix B

RI Microcosm Study Results



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Final Report

**Microcosm Presence/Absence Tests
on Groundwater from the Cornell-Dubilier OU-3 Superfund Site**

Malcolm-Pirnie Project Number 6739004

Summary

Introduction. BCI was asked by Janis Karn of Malcolm Pirnie, Inc. in Fair Lawn NJ for a cost quote per sample to perform twenty-one BCI Microcosm Presence/Absence Tests to determine the presence of microbial populations capable of complete anaerobic dechlorination of chlorinated ethenes to ethene, *Dehalococcoides ethenogenes* (Dhc), in well samples from the Cornell-Dubilier OU-3 Superfund Site in NJ.

Method. Anaerobic microcosm tests were performed on 21 groundwater samples collected in April 2010, and maintained for 60 to 90 days.

Result.

All samples contained anaerobic bacteria. The data showed that all well samples contained sulfate-reducing bacteria, nine samples contained methanogens, and eleven samples contained microbes capable of dechlorinating TCE to cDCE.

Four wells positive for D.ethenogenes. VC and ethene were produced from TCE and cDCE, in microcosms containing groundwater from four wells (14D-01, 14S-04, 16-05, and 16-07), indicating that the unique bacterium *D. ethenogenes* (Dhc) was active in those four samples.

The possibility is discussed that two groundwater samples containing native ethene and VC, but with negative test results for Dhc, represent areas where Dhc are soil-bound.

Methods

Sample Collection and Receipt.

Samples were obtained by Pirnie using 160 ml serum bottles that had been filled with Argon and provided with reducing agent to give 0.25 mM FeS. Bottles were completely filled with groundwater, sealed with Teflon-lined rubber septa affixed with crimped aluminum caps, and shipped priority overnight to BCI. Samples were received at BCI on 4/1/10, 4/7/10, 4/13/10, 4/14/10, and 4/15/10. On arrival BCI, samples received additional 0.04 mM Na₂S reducing agent by syringe through the septum. The purpose of the reducing agent was to remove traces of oxygen that may have entered the bottle during sampling.

Microcosm Setup At BCI, using two syringes simultaneously, 60 cc of Argon was injected into the bottle while 60 ml of groundwater was removed.

Analysis for Chlorinated compounds. The microcosms were incubated overnight to allow the chlorinated compounds and dissolved gasses to equilibrate to the headspace. Then 100 µL of headspace was removed by syringe and injected directly into a HP 5890 gas chromatograph according to EPA Method 5021A. Standards were prepared and analyzed similarly. ChemStation software was used to calculate response factors and calculate results.

Addition of TCE to five samples. Gas chromatography showed that the five ERT samples contained no chlorinated compounds. Therefore it was decided that these microcosms would be spiked with TCE to give 0.45 ppm. The results of the initial analysis are provided as Day 0 data in the attached spreadsheet. (These include the spike in the ERT samples.)

Analysis for Sulfate, Nitrate and Organic Acids. 150 µL aqueous samples were removed from the microcosms by syringe through the septa and analyzed by capillary ion electrophoresis according to EPA Method 6500 for sulfate, nitrate, and organic acids. Standards were analyzed with each batch. Response factors were calculated and results quantitated by Empower software. This method does not separate propionate and lactate. Analysis for lactate was conducted using Ion Chromatography according to EPA Method 300. The concentrations of native sulfate and nitrate are provided as day 1 data in the attached spreadsheet.

Addition of Electron Donor. The concentrations of electron acceptors (chlorinated compounds, sulfate and nitrate) were used to calculate the amount of donor that would be needed to reduce the anions as well as reductively dechlorinate the chlorinated compounds. For the ERT samples, this calculation included the added TCE. Small amounts of anaerobic stock solutions of donor were added by syringe through the septa. These included sodium lactate, NewmanZone Emulsified soy oil (containing 3% lactate), and ADL CornSweet (fructose and glucose sugars).

Addition of Other Amendments. Anaerobic stock solutions of the amendments were added on day 1 by syringe through the septum to give the following in mg/L: 40 NH₄-nitrogen, 60 phosphate, 2 Mg, 50 yeast extract, and 50 µg/L vitamin B₁₂. Trace elements were also added.

Test Duration. According to the subcontract agreement, eleven of the twenty-one samples were to undergo a 2-month day test, involving two Gas chromatographic (GC) contaminant/ethene analyses. Based on the 2-month data, ten samples were to be selected for a third GC analysis, which was conducted on ~ day 90.

Results.

The data are given in detail in Table 2, and summarized for each well in Table 1.

Anaerobic Microbial Processes.

- Nineteen samples reduced sulfate using lactate as donor, two required sugar.
- Nine samples produced methane.
- Eleven samples converted TCE to DCE.
- Of those, four samples converted DCE to VC and ethene.

Well	SO ₄ reduced (Lactate)	SO ₄ reduced (Sugar)	methane produced	TCE → DCE	DCE → VC	VC → Ethene	TCE + DCE → VC + Ethene	Result
14D-01	yes	—	yes	yes	yes	yes	93 %	positive
14D-03	yes	—	no	no	no	no		
14S-01	yes	—	no	yes	no	no		
14S-02	yes	—	no	yes	no	no		
14S-04	yes	—	yes	yes	yes	yes	76 %	positive
16-02	yes	—	yes	yes	no	no		
16-03	no	yes	yes	yes	no	no		
16-04	yes	—	no	yes	no	no		
16-05	yes	—	yes	yes	yes	yes	100 %	positive
16-07	yes	—	yes	yes	yes	yes	100 %	positive
20-01	yes	—	yes	yes	no	no		
20-03	yes	—	no	no	no	no		
20-05	yes	—	no	no	no	no		
20-07	yes	—	no	no	no	no		
20-08	yes	—	no	no	no	no		
24-04	no	yes	yes	yes	no	no		
ERT1-01	yes	—	yes	no	no	no		
ERT1-02	yes	—	no	no	no	no		
ERT1-04	yes	—	no	no	no	no		
ERT1-06	yes	—	no	no	no	no		
ERT1-08	yes	—	no	no	no	no		

Discussion of 14S-01 and 14S-02

Two of the site groundwater samples (14S-01 and 14S-02) arrived at BCI containing low but significant concentrations of ethene (>30 µg/L) and VC (>460 µg/L), but did not show significant increase in these critical products of reductive dechlorination by *D.ethenogenes* during the test period (85 days). BCI has occasionally worked with soil and groundwater samples from other sites, which indicate that DCE-dechlorinating bacteria can be tightly adsorbed to soil while not being detected in groundwater samples. We suggest that the soil near these two wells might contain DCE-dechlorinating bacteria.

14D-01 April 15, Lactate & minerals; April 29, EOL/sugar/Lac																		
		µM	µM	µM	µM	µM			mg/L	mg/L	mg/L	mg/L	mg/L		mg/L		nM	
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH
4/12	0	1.0	0.01	0.7	39	0.4	4/9		35	25	0	0	0		0	0		7.4
6/7	53	4.8	0.17	37	8	0	4/15	0	155	25	0	0	0	89		26		7.4→7.2
							4/27	12	155	0.6	0	47	2		< 4	40		7.1
pro/Lac means propionate and/or lactate																		
14D-03 April 15, Lactate & minerals; April 29, sugar; June 16, EOL																		
		µM	µM	µM	µM	µM			mg/L	mg/L	mg/L	mg/L	mg/L		mg/L		nM	
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH
4/12	0	0.5	0.02	0.06	3.7	0.1	4/9		60	48	3	0	0		0	0		7.4
6/7	53	0.3	0.02	0.06	3.9	0.1	4/15	0	176	48	3	0	0	178	0	26		7.5→7.0
							4/27	12	176	1	0	76	32		0	40		6.9
pro/Lac means propionate and/or lactate																		
14S-01 April 15, Lactate & minerals; April 29, EOL/sugar																		
		µM	µM	µM	µM	µM			mg/L	mg/L	mg/L	mg/L	mg/L		mg/L		nM	
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH
4/12	0	12	1.4	10	1690	738	4/9		194	38	8	0	0		0	0		7.3
6/7	53	11	1.3	12	2290	1	4/15	0	312	38	8	0	0	178	0	26		6.5→7.0
							4/27	12	312	7	0	25	105		0	40		6.8
pro/Lac means propionate and/or lactate																		
14S-02 April 15, Lactate & minerals; April 29, EOL/sugar																		
		µM	µM	µM	µM	µM			mg/L	mg/L	mg/L	mg/L	mg/L		mg/L		nM	
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH
4/12	0	13	1.1	7.5	1500	583	4/9		149	12	3	0	0		0	0		7.4
6/7	53	12	1.0	8.2	1820	0	4/15	0	288	12	3	0	0	89	< 2	26		6.6→7.2
							4/27	12	288	0.7	0	36	25		< 2	40		7.0
pro/Lac means propionate and/or lactate																		
14S-04 April 15, Lactate & minerals; April 29, EOL/sugar/Lac																		
		µM	µM	µM	µM	µM			mg/L	mg/L	mg/L	mg/L	mg/L		mg/L		nM	
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH
4/12	0	2.2	0.2	1.7	231	23	4/9		42	25	0	0	0		0	0		7.4
6/7	53	40	0.2	35	222	0	4/15	0	167	25	0	0	0	89	< 3	26		7.3
							4/27	12	167	1.4	0	54	6		< 3	40		7.3

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16-02																			April 21, Lactate & minerals; May 10, EOL/sugar/Lac																		
				μM		μM		μM		μM		μM				mg/L		mg/L		mg/L		mg/L		mg/L				mg/L				nM					
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH																			
4/16	0	444	0.4	4.6	11	1.7	4/16		59	22	0	0	0		0	0		7.1																			
6/14	54	428	0.4	5.1	13	0.2	4/21	0	179	22	0	0	0	89	0	20		7.2																			
							4/27	6	179	13	0	13	46		0	42		7.2																			
							5/6	15	177	0.8	0	43	9		0	44	>1930																				
																			pro/Lac means propionate and/or lactate																		
16-03																			April 21, Lactate & minerals; June 7, add sugar																		
				μM		μM		μM		μM		μM				mg/L		mg/L		mg/L		mg/L		mg/L				mg/L		nM							
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH																			
4/16	0	234	0.2	7.5	11	19	4/16		57	30	2	0	0		0	0		7.3																			
6/14	54	247	0.2	9.5	31	0	4/21	0	181	34	2	0	0	116	0	20		7.3																			
							4/27	6	181	34	0	0	97		0	42		7.3																			
							5/6	15	171	32	0	0	101		0	44	20																				
							5/17	26	161	31	0	0	93		0																						
							5/19	28				0	0	120	0																						
		Jun 7 add sugar					5/27	36	172	38	0	0	96		0																						
							6/9	49	158	34	0	0	95		2																						
							6/18	58	158	12	0	40	112		0																						
																			pro/Lac means propionate and/or lactate																		
16-04																			April 21, Lactate & minerals; May 18, EOL/sugar																		
				μM		μM		μM		μM		μM				mg/L		mg/L		mg/L		mg/L		mg/L				mg/L		nM							
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH																			
4/19	0	115	0.07	2.5	17	32	4/16		59	27	6	0	0		0	0		7.3																			
6/14	54	107	0.07	2.8	46	0	4/21	0	185	33	6	0	0	125	0	20		7.3																			
							4/27	6	185	33	0	0	98		0	42		7.3																			
							5/6	15	175	32	0	0	98		0																						
							5/17	26	165	0	0	44	39		0																						
																			pro/Lac means propionate and/or lactate																		
16-05																			April 15, Lactate & minerals; April 29, EOL/sugar/Lac																		
				μM		μM		μM		μM		μM				mg/L		mg/L		mg/L		mg/L		mg/L				mg/L		nM							
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH																			
4/12	0	155	0.07	0.6	12	0.3	4/12		56	30	0	0	0		0	0		7.3																			
6/8	54	211	12	0	0	0	4/15	0	184	30	0	0	0	107	<3	26		7.2																			
							4/27	12	184	0.8	0	89	0		<3	40		7.1																			

															pro/Lac means propionate and/or lactate				
16-07		April 15, Lactate & minerals; April 29, EOL/sugar/Lac																	
		µM	µM	µM	µM	µM			mg/L	mg/L	mg/L	mg/L	mg/L			mg/L	nM		
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH	
4/12	0	10	0	0.1	1.8	2.6	4/12		60	40	0	0	0		0	0		7.4	
6/8	54	320	0.1	5.3	0	0	4/15	0	181	40	0	0	0	142	< 2	26		7.2	
							4/27	12	181	1	0	99	6		< 2	40		7.1	
															pro/Lac means propionate and/or lactate				
ERT1-01		April 21, Lactate & minerals; May 10, EOL/sugar													Apr 27 spiked TCE				
		µM	µM	µM	µM	µM			mg/L	mg/L	mg/L	mg/L	mg/L			mg/L	nM		
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH	
4/28	0	36	0	0	0	3	4/16		51	29	10	0	0		0	0		7.3	
6/15	55	122	0	0	0	2.6	4/21	0	166	40	10	0	0	142	0	20		7.1	
							4/27	6	166	40	0	0	130		0	42		7.2	
							5/6	15	159	0	0	59	39		0				
															pro/Lac means propionate and/or lactate				
ERT1-02		April 21, Lactate & minerals; May 10, EOL/sugar													Apr 27 spiked TCE				
		µM	µM	µM	µM	µM			mg/L	mg/L	mg/L	mg/L	mg/L			mg/L	nM		
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH	
4/28	0	30	0	0	0	3	4/16		48	28	10	0	0		0	0		7.3	
6/15	55	24	0	0	0	2.4	4/21	0	168	27	10	0	0	142	0	20		7.2	
							4/27	6	168	27	0	11	94		0	42		7.2	
							5/6	15	174	0.6	0	52	41		< 2				
															pro/Lac means propionate and/or lactate				
ERT1-04		April 21, Lactate & minerals; May 10, EOL/sugar													Apr 27 spiked TCE				
		µM	µM	µM	µM	µM			mg/L	mg/L	mg/L	mg/L	mg/L			mg/L	nM		
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH	
4/28	0	38	0	0	0	3	4/16		49	23	11	0	0		0	0		7.3	
6/15	55	34	0	0	0	2.3	4/21	0	174	25	11	0	0	125	0	20		7.3	
							4/27	6	174	25	0	13	107		0	42		7.2	
							5/6	15	170	0.6	0	50	60		0				
															pro/Lac means propionate and/or lactate				

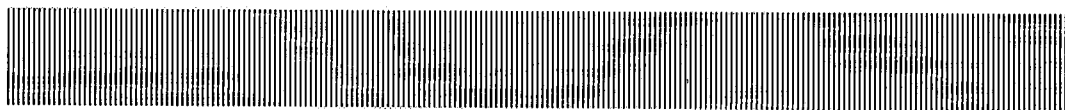
ERT1-06 April 21, Lactate & minerals; May 10, EOL/sugar														Apr 27 spiked TCE				
		μM	μM	μM	μM	μM			mg/L	mg/L	mg/L	mg/L	mg/L		mg/L		nM	
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH
4/28	0	31	0	0	0	3	4/16		65	24	9	0	0		0	0		7.2
6/15	55	26	0	0	0	2.5	4/21	0	192	27	9	0	0	125	0	20		7.2
							4/27	6	192	27	0	9	94		0	42		7.1
							5/6	15	185	0	0	52	34		0			
														pro/Lac means propionate and/or lactate				
ERT1-08 April 21, Lactate & minerals; May 10, EOL/sugar														Apr 27 spiked TCE				
		μM	μM	μM	μM	μM			mg/L	mg/L	mg/L	mg/L	mg/L		mg/L		nM	
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH
4/28	0	67	0	0	0	3	4/16		105	24	8	0	0		0	0		7.3
6/15	55	60	0	0	0	2.6	4/21	0	230	27	8	0	0	116	0	20		7.3
							4/27	6	230	27	0	4	102		0	42		7.2
							5/6	15	227	0	0	52	37		0			
														pro/Lac means propionate and/or lactate				
24-04 April 21, Lactate & minerals; June 7, add sugar																		
		μM	μM	μM	μM	μM			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L		nM	
Date	Day	Meth	Ethe	VC	cDCE	TCE	Date	Day	Cl	SO4	NO3	ac	pro/Lac	Lac	bu	Day	H2	pH
4/19	0	145	0.09	3.1	19	30	4/16		59	31	5	0	0		0	0		7.3
6/15	55	127	0.07	3.1	38	0	4/21	0	178	33	5	0	0	134	0	20		7.3
							4/27	6	178	33	0	0	104		0	42		7.2
							5/6	15	177	33	0	0	117		0	44	5	
							5/17	26	165	30	0	0	108		0			
							5/19	28				0	0	150	0			
							5/27	36	170	37	0	0	102		0			
						Jun 7 add sugar	6/9	49	161	35	0	0	108		0			
							6/18	58	166	24	0	31	155		0			
														pro/Lac means propionate and/or lactate				

United States Army Corps of Engineers, Kansas City
Draft Feasibility Study Report
Operable Unit 3: Groundwater
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Appendix C

Appendices C and D, Ex-Situ Treatment Technologies for Groundwater

**(from Presumptive Response Strategy and Ex-Situ
Treatment Technologies for Contaminated Ground
Water at CERCLA Sites. Directive 9283.1-12. EPA
540/R-96/023. October 1996.)**



APPENDIX C

Ex-Situ Treatment Technologies for Ground Water

Appendix C1: Ex-Situ Technologies Considered in Sample of 25 Sites

Appendix C2: Other Components Needed for Treatment Trains

Appendix C3: Information Needed for Selection of Technologies and Design of Treatment Train

Appendix C4: Advantages and Limitations of Presumptive Treatment Technologies

Appendix C1: Ex-Situ Technologies Considered in Sample of 25 Sites

Technologies that were **considered** for treatment of extracted ground in the sample of 25 sites reviewed in detail (EPA, 1996b) are listed below. These technologies were either considered in the feasibility study (FS), or considered and/or selected in the record of decision (ROD) or remedial design. The technologies are listed according to overall process type, and by design style within each type. Those technologies identified as **presumptive technologies** are also indicated. For further information on how presumptive technologies were identified, refer to Section 3.2 of this guidance and EPA, 1996b.

For Treatment of **Organic** Contaminants:

Presumptive Technologies:

Air stripping:

- Packed tower
 - Ambient temperature
 - Higher temperature
- Aeration methods
 - Ambient temperature
 - Higher temperature
- Cascade falls

Granular activated carbon (GAC)

Chemical/UV oxidation:

- Chemical oxidation alone
 - Ozone
 - Hydrogen peroxide
 - Chlorine compounds
 - Potassium permanganate
- Chemical with UV oxidation
 - Ozone
 - Hydrogen peroxide
- UV oxidation alone (photolysis)
- Alkaline chlorination (**for cyanide**)
- Unspecified oxidation methods

Aerobic biological reactors:

- Attached growth
 - Trickling filter
 - Rotating biological contactors
 - Fixed bed
- Suspended growth
 - Activated sludge
 - Sequencing batch reactors
 - Aeration ponds/lagoons
 - Unspecified suspended growth
- Unspecified aerobic reactors

For Treatment of **Metals**:

Chemical precipitation:

- Hydroxide precipitants
 - Sodium hydroxide
 - Lime
 - With prior chemical reduction
- Sulfide precipitants
 - Sulfur dioxide
 - Sodium sulfide
 - Sodium bisulfide/bisulfites
 - With prior chemical reduction
 - Unspecified sulfide precipitant
- Other precipitation methods
 - Ferrous sulfate
 - Potassium permanganate
 - Activated consumable element
 - Unspecified chemical precipitation

Ion exchange/adsorption:

- Fixed bed
 - Impregnated/synthetic resin
 - Activated alumina
- Electrodialysis
- Unspecified ion exchange

Electrochemical methods:

- Electrochemical reduction
- Magnetically activated

Aeration of Background Metals:

- Aeration basin
- Cascade aeration
- Other aeration methods

Appendix C1: Ex-Situ Technologies Considered in Sample of 25 Sites (continued)

For Treatment of **Organic Contaminants**:

Other Technologies Considered:

Chemical treatment:

- Hydrolysis
- Catalytic dehydrochlorination
- Catalytic dechlorination
- Chlorinolysis

Thermal Destruction:

- Incineration
- Calcination
- Wet air oxidation
- Supercritical water oxidation
- Microwave discharge/plasma

High temperature separation:

- Steam stripping
- Distillation

Membrane filtration:

- Reverse osmosis
- Ultrafiltration

Anaerobic biological treatment:

- Anaerobic biological reactor
- Enzymatic degradation

Liquid-liquid extraction:

- Solvent extraction
- Liquid carbon dioxide extraction

Evaporation:

- Evaporation basin

Land treatment:

- Surface spreading
- Spray irrigation

For Treatment of **Metals**:

Granular activated carbon (for metals)

Reverse Osmosis

Biological treatment of metals

Appendix C2: Other Components Needed for Treatment Trains ¹

Solid or Liquid Separation Technologies	Effluent Polishing Technologies ²	Vapor Phase Treatment Technologies ³
<ul style="list-style-type: none"> Oil/grease separation⁴ Filtration⁵ Coagulation⁵ (or flocculation) Clarification⁵ (or sedimentation) 	<ul style="list-style-type: none"> Activated carbon Ion exchange Neutralization 	<ul style="list-style-type: none"> Activated carbon Resin adsorption Catalytic oxidation Thermal incineration Acid gas scrubbing Condensation

General Sequence of Unit Processes Used in Aqueous Treatment Trains

Sequence	Unit Treatment Process	Treatment Stage
Begin	Equalize inflow Separate solid particles Separate oil/grease (NAPLs) Remove metals Remove volatile organics Remove other organics Polish organics ² Polish metals	Pretreatment Pretreatment Pretreatment Treatment Treatment Treatment Post-treatment Post-treatment
End	Adjust pH, if required	Post-treatment

NOTES:

- ¹ In addition to the presumptive technologies listed in the guidance, other treatment components are needed either prior to (pretreatment) or subsequent to (post-treatment) the presumptive technologies. This listing is not intended to be presumptive. Not listed are technologies that may be required for treatment residuals, such as spent carbon.
- ² Effluent polishing technologies are those used for the final stage of treatment prior to discharge, and can include pH adjustment (neutralization) as well as additional removal of aqueous constituents.
- ³ Vapor phase contaminants released during water treatment may need to be contained and treated. This includes organic contaminants volatilized during air stripping, from biological treatment, or other gases released from chemical oxidation, reduction or biologic processes (e.g., hydrochloric acid, hydrogen sulfide, methane, etc.).
- ⁴ Methods for separation of oil and/or grease from water include, but are not limited to, gravity separation and dissolved air floatation. These methods can be used to remove NAPLs from the extracted ground water.
- ⁵ These technologies can be used to remove solid particles at the beginning of the treatment train or for removal of other solids resulting from chemical precipitation, chemical/UV oxidation or biological treatment.

Appendix C3: Information Needed for Selection of Technologies and Design of Treatment Train

Information Needed	Purpose of Information
1. Total extraction flow rate: <ul style="list-style-type: none">● Total extracted flow● Flow variability● Uncertainty of estimate	<p>Inflow to the treatment system is the total flow from all extraction wells. Since this flow must also be discharged, large flows may determine the availability of some discharge options. Flow rate and concentration determines the mass loading (mass per unit water volume) of each contaminant entering the treatment system. The mass loading determines the dimensions and capacities of treatment vessels, and whether continuous flow or batch design are used for each treatment unit. Flow is also a factor for selecting among the presumptive treatment technologies because some are less cost effective for high or low flows.</p> <p>Variable inflow rates may require use of flow equalization tanks, batch instead of continuous flow operation or use of modular treatment units that can be added or subtracted from the treatment train. Some technologies can handle variable flow more easily than others. Variable extraction rates may result from short-term operational changes, seasonal changes or phased well installation.</p> <p>Uncertainty in the flow estimate can result from natural variability of aquifer properties over the site, and from the method used to measure these properties. Since flow is a critical design parameter, additional characterization may be needed to reduce the level of uncertainty. Estimates of the total extraction rate should be based on pumping type aquifer tests, since this method provides a much better estimate of average aquifer properties than other methods.</p>

Appendix C3: Information Needed for Selection of Technologies and Design of Treatment Train (continued)

Information Needed	Purpose of Information
2. Discharge options and effluent requirements: <ul style="list-style-type: none"> ● Options available ● Target effluent concentrations, each option <ul style="list-style-type: none"> - Contaminants - Contaminant degradation products - Treatment additives - Natural constituents - Water quality parameters ● Other requirements, each option <ul style="list-style-type: none"> - Regulatory - Operational ● Community concerns or preferences 	<p>Options for discharge of treated ground water could include: discharge to surface waters; discharge to a drinking water system; reuse or recycling for other purposes (e.g., industrial processes); infiltration or reinjection to shallow subsurface or reinjection to the same aquifer; or discharge to POTW. Target effluent concentration levels for both contaminants and naturally occurring constituents may be markedly different for each discharge option.</p> <p>Effluent requirements could include those for chemicals added during treatment, contaminant degradation products, naturally occurring constituents (e.g., arsenic), and water quality parameters (e.g., suspended solids) in addition to maximum concentration levels for chemicals of concern. These requirements will determine the overall level of treatment needed, which in turn determines the type of components needed in the treatment train and is a critical factor in selecting appropriate treatment technologies.</p> <p>Each discharge option may have different water quality requirements for the treated effluent, from both a regulatory and operational standpoint. For example, reinjection to the subsurface must meet substantive federal and/or state requirements for underground injection (regulatory) as well as minimize chemical and biological clogging of injection wells or infiltration lines (operational). Use of the best available technology (BAT) could also be a regulatory requirement. The affected community may also have concerns or preferences regarding the type of discharge.</p> <p>Target effluent concentrations determine the overall removal efficiency the treatment train must attain for each constituent. For example, if the target effluent level is 10 mg/L and the inflow concentration is 1000 mg/L, then the treatment train must attain an overall removal efficiency of 99.0 percent ($1000 - 0.99(1000) = 10$). The treatment train may need to include more than one type of technology, or multiple units of a single technology, in order to attain the required overall removal efficiency.</p>

Appendix C3: Information Needed for Selection of Technologies and Design of Treatment Train (continued)

Information Needed	Purpose of Information
<p>3. Water quality of treatment influent:</p> <ul style="list-style-type: none"> ● Contaminant types and concentrations: <ul style="list-style-type: none"> - Inorganic chemicals - Organic chemicals - Concentration changes over time - Nonaqueous phase liquids (NAPLs) ● Naturally occurring constituents: <ul style="list-style-type: none"> - Major cations (metals) and anions - Organic chemicals - Radionuclides 	<p>Contaminant types and concentrations must be estimated for the total flow entering the treatment system. Since some technologies are more effective in removing certain contaminant types, this is an important technology selection factor. Inflow concentrations are needed to determine the removal efficiency of the treatment train, as discussed above.</p> <p>The design should consider the potential for inflow concentrations to change over time. Contaminant concentrations usually decrease as remediation progresses. Also, short term increases may occur if a "hot spot" of more highly contaminated ground water is captured by the extraction system. Samples obtained from pumping type aquifer tests provide better estimates of average contaminant concentrations, because such samples are obtained from a relatively large aquifer volume.</p> <p>If present, subsurface NAPLs (refer to Appendix A1) may become entrained in the extracted ground water. These immiscible liquids should be removed in a pretreatment step (process used prior to other treatment methods). Also, a specialized extraction system may be needed to remove free-phase NAPLs from the subsurface.</p> <p>Naturally occurring or non-site related constituents may need to be removed to prevent interference with treatment processes and may be a factor in technology selection. Metals such as iron, manganese, and calcium can leave mineral deposits (scaling) on air stripper packing and on activated carbon or other treatment media. If not accounted for, these metals can also cause premature exhaustion of ion exchange capacity and increased consumption of reagents in chemical oxidation or precipitation processes. Iron also promotes biological fouling in air strippers. Heavy metals (e.g., lead, mercury) and cyanides can be toxic to microorganisms in biological reactors. Metals can also form deposits on well screens of extraction or reinjection wells (encrustation) or promote biological fouling (clogging) on well screens.</p>

Appendix C3: Information Needed for Selection of Technologies and Design of Treatment Train (continued)

Information Needed	Purpose of Information
3. Water quality of influent (continued):	<p>Dissolved organic constituents (e.g., from decay of organic materials or from landfill leachate) can interfere with adsorption of targeted compounds and can cause premature exhaustion of activated carbon. Metal-organic complexes can interfere with chemical oxidation or precipitation processes.</p>
<ul style="list-style-type: none"> ● Other water quality parameters: <ul style="list-style-type: none"> - Indicator parameters - Design parameters 	<p>If present, naturally occurring radionuclides can accumulate in treatment media or residuals (e.g., activated carbon or chemical sludges) resulting in potential exposure hazards for personnel and additional transportation and disposal considerations.</p>
	<p>Other water quality parameters are used as effluent quality standards, indicator parameters, or design parameters for treatment processes. Indicator parameters are used to indicate the presence of other constituents. For example, total dissolved carbon (TDC) is a measure of the relative level of dissolved organic constituents. Gross alpha and gross beta particle activity are relatively simple measurements that indicate the relative abundance of naturally occurring radionuclides. Other indicator parameters include: total dissolved solids (TDS), chemical oxygen demand (COD), biological oxygen demand (BOD) and total suspended solids (TSS). Temperature and pH are design parameters for most treatment processes.</p>
	<p>Also, high levels of total suspended solids (TSS) in extracted ground water may indicate that extraction wells are not properly designed or developed. Most treatment technologies require that suspended solids in excess of certain level be removed during pretreatment, where acceptable levels may differ for each technology.</p>

Appendix C3: Information Needed for Selection of Technologies and Design of Treatment Train (continued)

Information Needed	Purpose of Information
<p>4. Treatability information:</p> <ul style="list-style-type: none"> ● From technical literature ● Treatability studies <ul style="list-style-type: none"> - Laboratory screening - Bench-scale testing - Pilot-scale testing ● Modeling predictions ● Projections of effluent quality 	<p>Treatability information is needed to select technology types and design styles from among the presumptive technologies; and for selection and design of other components of the treatment train. The particular mix of contaminants and naturally occurring constituents can vary considerably for different sites. Treatability information is available in the technical literature for some technologies, including air stripping and granular activated carbon (GAC).</p> <p>Treatability studies include 1) laboratory screening, 2) bench-scale testing, or 3) pilot-scale testing. These studies may begin with any tier and skip tiers that are not needed (see Section 3.4 of guidance). Computer models for predicting treatment performance are available for some technologies.</p> <p>In general, treatability studies should be performed prior or during the design of any system expected to provide long-term treatment of extracted ground water, including systems using presumptive technologies. Treatability studies are needed to accurately predict the effectiveness and cost of a technology for a given site, including construction and operating costs; and the costs of other components of the treatment train. Optimizing the cost effectiveness of the treatment train (i.e., minimizing the total cost per unit volume of water treated) is especially important for systems designed to operate over a long time period.</p> <p>Treatability studies may reveal unexpected site conditions, such as the presence of naturally occurring compounds that interfere with the planned treatment process or that metal contaminants can be effectively removed by removing mineral solids. Such studies are also needed to determine pretreatment requirements, and requirements for treating aqueous, vapor and solid waste streams resulting from a particular treatment process. Treatability studies are needed to determine optimum chemical reagents and reagent quantities for pH adjustment; oxidation, reduction or precipitation of contaminants; and parameters for design of biological and other reactors.</p> <p>Treatability studies should be performed on samples obtained from pumping type aquifer tests instead of from monitoring wells, because such samples are more representative of contaminated ground water that will enter the treatment system. Samples obtained for treatability studies should be obtained after several hours of pumping.</p>

Appendix C4: Advantages and Limitations of Presumptive Treatment Technologies

Technology	Advantages	Limitations
<i>Treatment Technologies for the Removal of Organic Contaminants</i>		
Air Stripping	<ul style="list-style-type: none"> • Successfully used in hundreds of groundwater applications • Low operating cost relative to other technologies (e.g., energy usage is relatively low). • Operationally simple system requiring a minimum of operator assistance. • Treatability studies often not required for selection or design, but are recommended. • Trained contractors available to implement the technology. 	<ul style="list-style-type: none"> • Contaminants transferred to air, and treatment of air emissions may be required. • Pretreatment for metals removal and pH control may be needed to reduce fouling and corrosion. • Post-treatment (polishing) may be required. • Large surges in influent concentrations can reduce removal efficiency because the efficiency for an individual compound is fixed regardless of influent concentrations. • Air stripping is not as effective for compounds with low Henry's law constants or high solubilities.^{b,c} • Cold weather can reduce efficiency.
Granular Activated Carbon	<ul style="list-style-type: none"> • Successfully used for contaminated ground water at many Superfund and underground storage tank sites. • Operationally simple system requiring a minimum of operator assistance. • Regularly used as a <u>polishing</u> step following other treatment technologies. • Treatability studies generally not required, but are recommended (information is available from carbon vendors). • Trained contractors available to implement the technology. • Generally a cost-effective alternative as single- step treatment for flows less than about 3 gpm.^d 	<ul style="list-style-type: none"> • Activated carbon is generally too costly for use as a single-step treatment if ground-water chemistry requires high carbon usage rates. • Contaminants are not destroyed but are transferred to another media (i.e., spent carbon must be regenerated or disposed of properly). • Pretreatment for suspended solids removal is often required. • Pretreatment for metals removal and pH control may be needed to reduce fouling and corrosion. • Organic compounds that have low molecular weight and high polarity are not recommended for activated carbon (e.g., acetone). • Naturally occurring organic compounds may exhaust carbon bed rapidly and may interfere with the adsorption of targeted chemicals.

Appendix C4: Advantages and Limitations of Presumptive Treatment Technologies (continued)

Technology	Advantages	Limitations
Chemical/ UV Oxidation	<ul style="list-style-type: none"> Where oxidation is complete, organic contaminants are <u>destroyed</u> and not transferred to other media; minimal residuals generated. Effective on a wide variety of volatile and semivolatile organics, including chlorinated organics, as well as cyanide and some metals. Operating costs can be competitive with air stripping and activated carbon. 	<ul style="list-style-type: none"> Incomplete oxidation will leave original contaminants and possibly toxic oxidation products; activated carbon polishing may be required. Capital costs may preclude small-scale applications, especially for ozone systems. Metals may precipitate during oxidation, requiring filtration post-treatment and residuals disposal. UV light sources are subject to fouling and scaling from solids, iron compounds, carbonates, etc. Pretreatment may be required to remove these substances. Process must be closely monitored to ensure contaminant destruction and to prevent safety hazards. Peroxide and other chemical oxidants must be properly stored and handled. Site-specific treatability studies are necessary (process may require large quantities of oxidizer to destroy target compound(s) if reactive nontarget compounds are present).
Aerobic Biological Reactors	<ul style="list-style-type: none"> Organic contaminants <u>degraded</u>, often with minimal cross-media environmental impacts. Proven effective for many organic compounds. Some systems (e.g., trickling filters and rotating biological contactors) have minimal energy requirements and generally low capital and operating costs. Can be designed to require a minimum of operator attention. Relatively simple, readily available equipment. Trained contractors available to implement the technology. 	<ul style="list-style-type: none"> A residual organic sludge is generated that must be disposed of properly. Some compounds are difficult or impossible to degrade (recalcitrant) or slow to degrade. Difficulties acclimating microorganisms to contaminants are possible; requires longer startup time than other technologies to achieve effective steady-state performance Volatile organics may require air emission controls or pretreatment to remove them. Variations in flow or concentration may require significant operator attention to prevent microorganisms from being killed. Cold weather can cause operational difficulties. Treatability studies are needed for selection and design. Pretreatment may be needed to remove contaminants toxic to the microorganisms, such as heavy metals. Low organic loading and the potential for supplementary nutrients and food sources must be considered.

Appendix C4: Advantages and Limitations of Presumptive Treatment Technologies (continued)

Technology	Advantages	Limitations
<i>Treatment Technologies for the Removal of Inorganic Contaminants</i>		
Chemical Precipitation	<ul style="list-style-type: none"> Most commonly used method for removing soluble heavy metal ions from contaminated water. Pretreatment for solids and iron generally not required. <p><u>Hydroxide Precipitation</u></p> <ul style="list-style-type: none"> Reliable method, chemicals relatively easy to handle, and not costly. <p><u>Carbonate Precipitation</u></p> <ul style="list-style-type: none"> Reliable method, calcium carbonate easy to handle, and not costly. Effectively removes a variety of soluble metals. <p><u>Sulfide Precipitation</u></p> <ul style="list-style-type: none"> Reliable method. High removal efficiency over a broader pH range. Relatively insensitive to most chelating agents. Can remove chromates and dichromates without reducing hexavalent chromium to trivalent form if ferrous ions are present or added. 	<ul style="list-style-type: none"> A residual sludge is generated that must be treated and/or disposed of properly; metals are not usually easy to recover from sludge. Up to four times stoichiometric chemical additions may be required, especially for sulfide precipitation (see below). <p><u>Hydroxide Precipitation</u></p> <ul style="list-style-type: none"> Organics or complexing ions may form chelates/complexes instead of insoluble metal hydroxides. Optimum pH is different for each metal hydroxide, one pH may not effectively treat all soluble metal ions; successive treatments may be required. pH must be controlled within a narrow range. Naturally occurring sulfate in ground water may react with lime to form gypsum, which increases sludge, can clog filters, and can coat pipelines (caustic soda addition can reduce this problem but increases costs and dissolved solids [sodium salts] that must be removed from treated ground water). <p><u>Carbonate Precipitation</u></p> <ul style="list-style-type: none"> Calcium carbonate is not effective for ground water with high alkaline content. Pretreatment to remove organic, chelating, or oil and grease contaminants may be required. <p><u>Sulfide Precipitation (Soluble Sulfide)</u></p> <ul style="list-style-type: none"> Excess sulfide ions that are not precipitated remain in solution. They may be removed by using aeration to convert them from ionic to oxide form (sulfate). pH control between 8 and 9.5 is required to avoid release of hydrogen sulfide gas. Cost is high compared to hydroxide and carbonate precipitation <p><u>Sulfide Precipitation (Insoluble Sulfides)</u></p> <ul style="list-style-type: none"> Ferrous sulfide is used in amounts greater than that required by stoichiometric considerations. Produces more sludge than soluble sulfide or hydroxide processes.

Appendix C4: Advantages and Limitations of Presumptive Treatment Technologies (continued)

Technology	Advantages	Limitations
<i>Treatment Technologies for the Removal of Inorganic Contaminants (continued):</i>		
Ion Exchange/ Adsorption	<ul style="list-style-type: none"> • High removal efficiencies for heavy metals. • Suitable for use as a polishing step after other technologies. • Technology is reasonably well understood. • On-site backflushing of exchange media allows immediate reuse. 	<ul style="list-style-type: none"> • Resins are usually costly and may not be cost-effective for large treatment loadings. • Generates large volume of backflush solution (approximately 2.5 to 5% of the original ground-water flow rate) that is concentrated in the metals removed and requires treatment or disposal. • Requires bench-scale testing to determine operational requirements and suitability of prospective resins. • Beds can be fouled by particulate matter, oxidizing agents, oils, greases, biological growths, and intra-bed precipitates; therefore, pretreatment may be needed. • Resins may be irreversibly harmed by aromatics and certain other organic compounds; and by iron, manganese, and copper if enough dissolved oxygen is present. Pretreatment may be needed. • Spent resins require treatment before disposal.
Electro-chemical Methods	<ul style="list-style-type: none"> • High removal efficiencies for certain heavy metals. • Can treat both metals and cyanide simultaneously. • Technology is reasonably well understood. • Requires little floor space due to short residence time for hexavalent chromium reduction. • Requires minimal operator attention. • Low operating costs compared to chemical reduction or precipitation. • Requires no chemical addition. 	<ul style="list-style-type: none"> • Particulate matter, oxidizing agents, oils, greases, biological growths may reduce process efficiency; therefore, pretreatment may be needed. • Hexavalent chromium reduction generates a heavy metal precipitate that must be removed from solution in a subsequent clarification or settling process. • A heavy metal sludge residual may be generated that may require treatment (dewatering and/or fixation) and that will require disposal. • A spent acid rinse solution may be generated that requires treatment or disposal. • Electrodes must be replaced occasionally.

NOTES:

^a U.S. Environmental Protection Agency. 1991. Engineering Bulletin: *Air Stripping of Aqueous Solutions*. EPA/540/2-91/022. 8 pp.

^b B. Lamarre. 1993. Selecting an air stripper (what to consider!) *The National Environmental Journal*; 26-29.

^c G. M. Long. 1993. Clean up hydrocarbon contamination effectively. *Chemical Engineering Progress*; 58-66.

APPENDIX D

Descriptions of Presumptive Treatment Technologies

Appendix D1:	Air Stripping
Appendix D2:	Granular Activated Carbon
Appendix D3:	Chemical/UV Oxidation
Appendix D4:	Aerobic Biological Reactors
Appendix D5:	Chemical Precipitation
Appendix D6:	Ion Exchange/Adsorption
Appendix D7:	Electrochemical Methods
Appendix D8:	Aeration of Background Metals

Appendix D1: Air Stripping

Air stripping uses volatilization to transfer contaminants from ground water to air. In general, water is contacted with an air stream to volatilize dissolved contaminants into the air stream. Stripping of a specific chemical depends on the equilibrium vapor pressure of that chemical as expressed by its Henry's law constant.

Applicability

Air stripping is *applicable* to most of the volatile organic compounds (VOCs) as well as volatile inorganics such as ammonia and hydrogen sulfide. VOCs with high solubility in water (e.g., acetone) are more difficult to air strip. Air stripping is *potentially applicable* to certain halogenated semi-volatile organic compounds (SVOCs). It is *not applicable* to nonhalogenated SVOCs; heavy organics such as PCBs, dioxins/furans and pesticides; or inorganic metal compounds (U.S. EPA, 1991).

Air stripping is most effective for contaminants with a dimensionless (molar volume) Henry's law constant greater than 0.01 (or 2.4×10^{-4} atm-m³/gmol at 25° C). (Henry's law constants are available in U.S. EPA [1990]). Removal efficiencies greater than 99 percent are difficult to achieve for certain compounds. In general, other treatment technologies will be required for such chemicals when ground-water concentrations are high (e.g., above 10,000 ppm or 1 percent).

Contaminant Fate

Contaminants are not destroyed by air stripping but are physically separated from contaminated ground water and transferred to air. Depending on the level of contaminants in the air discharge, the contaminated air stream may need further treatment. Additional polishing treatment of the aqueous effluent also may be necessary, depending on discharge requirements.

Design

Air strippers are designed for a specific target chemical (either the predominant contaminant or the most difficult-to-strip contaminant) with a desired target removal efficiency. The air stripping process is well understood and the technology is well developed. Air stripping has an extensive track record in a variety of applications.

The most frequently used configuration is a packed tower equipped with an air blower. The ground water is fed into the top of the stripper and the air is introduced at the bottom, creating a countercurrent gas-liquid contact. Random plastic packing is frequently used to improve gas-liquid contact. Structured packing and steel packing may also be used. Packed-tower air stripper design involves specification of stripper column diameter and packing height for a specified ground-water flow rate and air-to-water ratio. Shallow-tray aeration devices provide an alternative gas-liquid contacting system that provides a more compact, lower profile system that is less subject to fouling.

Alternative Techniques/Enhanced Methods

- For high flow rates (over 1,000 gpm), cooling towers (large structures with cascading water primarily used to cool water using countercurrent ambient air flow) may provide a cost-effective alternative to conventional packed towers.
- Shallow tray air strippers or diffused tank aeration units are less susceptible to fouling problems than packed towers and may be preferable where the water to be treated contains high concentrations of certain inorganics (e.g., iron).

Appendix D1: Air Stripping (continued)

Alternative Techniques/Enhanced Methods (continued)

- Because the efficiency of air stripping increases at higher temperatures, increasing the influent ground-water temperature (typically about 55° F) using a heat exchanger can increase the stripper's removal efficiency, especially for less volatile contaminants.
- Steam stripping methods, which use steam rather than air as the stripping medium, can be used to remove highly soluble contaminants and SVOCs not usually amenable to air stripping. However, operation costs for steam stripping can be two to three times greater than air stripping, depending on the cost of steam. In this guidance, these methods are not considered a type of air stripping and are not identified as a presumptive technology for ex-situ treatment of ground water.

Pre/Post-treatment

- Pretreatment to remove iron and other metals and to control hardness may be necessary to reduce fouling and mineral deposition in packed tower air strippers.
- Granular activated carbon is sometimes used to polish the treated water from an air stripper to further reduce organic contaminant levels and meet discharge requirements.
- Contaminants in the air discharge may be reduced by activated carbon adsorption, catalytic oxidation, or incineration to meet air emission requirements.

Selected References

- Lamarre, B. 1993. Selecting an air stripper (what to consider!). The National Environmental Journal: 26-29.
- Nyer, E.K. 1985. Groundwater Treatment Technologies. Van Nostrand Reinhold, New York, NY. 187 pp.
- Nyer, E.K. 1993. Practical Techniques for Groundwater and Soil Remediation. CRC Press, Inc., Boca Raton, FL. 214 pp.
- Okoniewski, B.A. 1992. Remove VOCs from wastewater by air stripping. Chemical Engineering Progress: 89-93.
- U.S. EPA Environmental Protection Agency. 1990. Hazardous Waste Treatment, Storage, and Disposal Facilities (TSDF) - Air Emission Models. EPA/450/3-87-026. Office of Air Quality Planning and Standards, Research Triangle Park, NC. Appendix D.
- U.S. Environmental Protection Agency. 1991. Engineering Bulletin: Air Stripping of Aqueous Solutions. EPA/540/2-91/022. Office of Research and Development, Cincinnati, OH. 9 pp.

Appendix D2: Granular Activated Carbon

Activated carbon removes contaminants from ground water by adsorption. The adsorption process takes place in three steps: (1) contaminant migration to the external sorbent surface; (2) diffusion into the sorbent pore structure; and (3) adsorption onto the sorbent surface. The principal form of activated carbon used for ground-water treatment is granular activated carbon (GAC). GAC is an excellent sorbent due to its large surface area, which generally ranges from 500 to 2,000 m²/g.

Applicability

GAC is *applicable* to a wide variety of contaminants including: halogenated volatile and semivolatile organics, nonhalogenated volatile and semivolatile organics, PCBs, pesticides, dioxins/furans, most organic corrosives, metals, radioactive materials, inorganic cyanides, and certain oxidizers. GAC is *potentially applicable* to certain organic cyanides, and it is *not applicable* to asbestos, inorganic corrosives, and reducers (U.S. EPA, 1991). GAC is sometimes used alone for ground-water treatment. However, GAC is typically used for polishing aqueous effluents or controlling air emissions from other treatment technologies.

The adsorption capacity of activated carbon varies for specific organic compounds and for different types of GAC (based on the origin of coal and the percent binder used in the manufacture of the GAC). Contaminant-specific adsorption isotherms for a given type of GAC are generally available from the carbon manufacturer.

Contaminant Fate

Contaminants are not destroyed by carbon adsorption, but are physically separated from contaminated water and transferred to carbon. After exhaustion, the spent carbon may be reactivated, regenerated, incinerated, or disposed of. Thermal reactivation and incineration destroy most or all adsorbed organic contaminants. Steam or hot gas regeneration is not appropriate for spent GAC from treatment of contaminated ground water but can be used for spent GAC from air emission control devices. GAC used for metals sorption may require disposal. If disposed of, spent GAC may have to be managed as a hazardous waste.

Design

Activated carbon is a well-developed, widely used technology with many successful ground-water treatment applications, especially for secondary polishing of effluents from other treatment technologies. Contaminated ground water is contacted with a fixed GAC bed in a vessel. Flow direction is generally vertically downward, although an upward flow configuration is also possible. Fixed-bed configurations are also used for air emission control.

Adsorber design involves determining total carbon requirements and the number and dimensions of vessels needed to house the carbon. The amount of carbon required for a given application depends on the loading of adsorbable constituents in ground water (or contaminated air stream), the carbon's adsorption capacity for these constituents, and the carbon reactivation (or regeneration) frequency. Depending on the ground-water suspended solids content, it may be necessary to periodically backwash down flow carbon beds to relieve pressure drop associated with solids accumulation.

Alternative Techniques/Enhanced Methods

- Staged bed (multiple beds operated in series) and pulsed bed (carbon beds operated with nearly continuous "pulsed" addition of fresh carbon and withdrawal of spent carbon) designs can be used if higher removal efficiencies are required.

Appendix D2: Granular Activated Carbon (continued)

Alternative Techniques/Enhanced Methods (continued)

- Because the adsorption capacity of GAC is much higher for gas phase treatment than for liquid phase treatment, it is often more economical to use an air stripper followed by gas phase GAC to treat the air stripper exhaust than to use GAC alone for ground-water treatment.
- **GAC is not identified as a presumptive technology for removal of metals dissolved extracted ground water. Spent carbon used for metals removal can be difficult to regenerate and may require treatment and/or disposal as a hazardous waste.** Although GAC can remove low concentrations of certain metals, it has not been widely used for this purpose (U.S. EPA, 1991).

Pre/Post-treatment

- Pretreatment may be required to remove natural organic matter, such as fulvic and humic acids, that may interfere with the adsorption of the target contaminants or rapidly exhaust the GAC.
- Naturally occurring **radionuclides**, if present in ground water, can accumulate in the GAC during treatment, **which could result in potential exposure hazards for operating personnel and the spent carbon may require treatment and/or disposal as hazardous waste.**
- Thermal reactivation, using heat alone or steam, is typically used as a post-treatment method for the spent carbon. The carbon is reactivated in a high-temperature reactor under reducing conditions. Most organic contaminants are thermally degraded during the reactivation process.

Selected References

- Long, G.M. 1993. Clean up hydrocarbon contamination effectively. *Chemical Engineering Progress*, 89(5):58-67.
- Stover, E.L. 1988. Treatment of herbicides in ground water. *Ground Water Monitoring Review*: 54-59.
- Stenzel, M.H. 1993. Remove organics by activated carbon adsorption. *Chemical Engineering Progress*: 36-43.
- U.S. Environmental Protection Agency. 1991. *Engineering Bulletin: Granular Activated Carbon Treatment*. EPA/540/2-91/024. Office of Emergency and Remedial Response, Washington, D.C. 8 pp.

Appendix D3: Chemical/UV Oxidation

Chemical oxidation uses chemical oxidizing agents to destroy toxic organic chemicals and cyanide compounds (CN) in ground water. Commonly used oxidizing agents include: ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide. Ozone and hydrogen peroxide are generally preferred for removing organics and CN from ground water because chlorine-based oxidants can produce toxic byproducts (e.g., HCl, chlorinated organics). Ultraviolet light (UV) is often used in conjunction with ozone and/or hydrogen peroxide to promote faster and more complete destruction of organic compounds (reaction rates may be increased by factors of 100 to 1,000).

Applicability

Chemical oxidation is *applicable* to both volatile and semivolatile organic compounds and cyanide compounds. Chemical oxidation is *potentially applicable* to PCBs, dioxins/furans, and metals (oxidation can be used to precipitate metals under certain conditions). Chemical oxidation is *not applicable* to asbestos and radioactive materials (U.S. EPA, 1991).

Chemical oxidation generally is effective for concentrations less than 500 µg/L, but has been used for certain compounds at concentrations ranging up to several thousand mg/L. UV can enhance the oxidation of compounds that are resistant to chemical oxidation alone (e.g., PCBs). Iron or copper catalysts may be required for efficient destruction of certain organic compounds (e.g., phenols).

Contaminant Fate

Complete oxidation decomposes hydrocarbons into carbon dioxide and water, although chlorinated organic compounds also yield chloride ions. CN is oxidized to ammonia and bicarbonate by hydrogen peroxide in an alkaline environment. If oxidation is incomplete, toxic constituents may remain, or intermediate degradation products can be formed that may be toxic. These toxic substances may be removed using GAC as a secondary or polishing treatment step.

Design

Chemical oxidation is a proven and effective technology that is carried out in either batch or continuous reactors. Oxidants are generally added to contaminated ground water in a mixing tank prior to introduction into the reaction vessel (reactor). The use of ozone as the oxidizing agent requires an onsite ozone generator and an ozone decomposition unit or other ozone emission control device. The use of hydrogen peroxide as the oxidizing agent requires storage tanks and special handling protocols to ensure operator safety. The use of chlorine as the oxidizing agent may produce HCl gas. If HCl is produced, an acid gas removal system may be necessary.

UV lamps, if used, are typically enclosed in quartz tubes submerged inside the reaction vessel. The tubes are subject to fouling or scaling from compounds such as iron oxide or calcium carbonate and from biological flocs from microorganisms in ground water. If fouling occurs, oxidation rates are drastically reduced.

Site-specific treatability studies are generally recommended for chemical oxidation systems. Extensive pretreatment may be required to condition ground water for effective oxidation. If UV lamps are used, the studies must evaluate the potential for fouling or scaling of the quartz tubes at the ground-water composition, oxidant concentration, and UV intensity conditions anticipated for long-term system operation. If fouling or scaling is likely, pretreatment and/or physical methods for keeping the tubes clean (e.g., wipers) may be required. If metals are to be removed by oxidation, solids should be removed by clarification or filtration prior to UV oxidation. Provisions for removing precipitated metal sludges also may be necessary.

Appendix D3: Chemical/UV Oxidation (continued)

Alternative Techniques/Enhanced Methods

- UV radiation can be used in combination with a chemical oxidizing agent to increase the effectiveness of oxidation, especially for difficult-to-oxidize compounds.
- Metal catalysts, such as iron or copper, can be used in combination with a chemical oxidizing agent to increase the effectiveness of oxidation for certain types of compounds.
- Hydrodynamic cavitation is an innovative technology recently demonstrated under EPA's SITE program that uses forced cavitation of gas to enhance destruction of organics during UV oxidation processes.

Pre/Post-treatment

- Pretreatment may be necessary to remove solids, microorganisms, calcium carbonate, iron oxides, and/or other metals that can interfere with the oxidation process or UV transmission. A pretreatment sequence of precipitation, flocculation, clarification, and/or filtration steps may be necessary.
- Post-treatment of the aqueous effluent with GAC may be necessary if destruction is not complete or if toxic byproducts are formed during oxidation.
- If toxic metals precipitate during the oxidation process, treatment and/or proper disposal of the resulting sludge may be required.

Selected References

U.S. Environmental Protection Agency. 1990. *CERCLA Site Discharges to POTWs Treatability Manual*. EPA/540/2-90/008. Office of Emergency and Remedial Response. PB91-921269/CCE. NTIS. Springfield, VA. pp. 11-7 to 11-17.

U.S. Environmental Protection Agency. 1991. *Engineering Bulletin: Chemical Oxidation Treatment*. EPA/540/2-91/025. Office of Emergency and Remedial Response, Washington, D.C. 8 pp.

U.S. Environmental Protection Agency. 1993. *Superfund Innovative Technology Evaluation Program. Technology Profiles. Sixth Edition*. EPA/540/R-93/526. Office of Research and Development, Washington, DC.

U.S. Navy. 1993. *UV/Oxidation Treatment of Organics in Ground Water*. NEESA Document Number 20.2-051.7. Navy Energy and Environment Support Activity, Port Hueneme, CA. 11 pp.

Appendix D4: Aerobic Biological Reactors

Biological reactors use microorganisms to degrade organic contaminants in ground water in ex situ reactors. There are two basic types of ex situ biological treatment processes: aerobic reactors and anaerobic reactors. Aerobic reactors use oxygen to promote biodegradation and are widely used. Anaerobic reactors degrade organics in the absence of oxygen. This guidance focuses on aerobic biological treatment because anaerobic treatment processes are not widely used for ground-water treatment.

Applicability

Aerobic biological reactors are *applicable* to a wide variety of halogenated and nonhalogenated volatile and semivolatile organics. Aerobic biological reactors are *potentially applicable* to heavy organics, such as PCBs and certain pesticides, and organic and inorganic cyanides, but are generally not as effective for such recalcitrant compounds. Aerobic processes are *not applicable* to metals, asbestos, radioactive materials, or corrosive or reactive chemicals (U.S. EPA, 1992).

Contaminant Fate

Organic compounds are decomposed to carbon dioxide and water (aerobic processes) or to methane and carbon dioxide (anaerobic processes). Volatile organics are also removed by volatilization as a competing mechanism. Microbial growth produces an excess organic sludge (biomass) that must be disposed of properly. This sludge may concentrate metals and recalcitrant organic compounds that are resistant to degradation. Biodegradation may produce decomposition byproducts that are emitted to the air or dissolved in the effluent, and these decomposition byproducts may require additional treatment.

Design

Ex situ biological treatment of ground water is conducted in bioreactors. The primary factors influencing bioreactor design are the microbial organic utilization rates and the peak organic loading rate (i.e., flow rate times organic concentration). Treatability tests are necessary to determine these and other design parameters. Under most circumstances, bioreactors require a significant startup time to acclimate the microorganisms to the specific contaminants being treated before the bioreactor will operate at optimal degradation rates. There are two general types of bioreactor design:

- In **suspended growth** reactors, microbes are kept suspended in water using mechanical aerators or diffused air systems. These aeration systems also keep the solution well mixed, improving contact between microbes and dissolved contaminants and supplying oxygen to the system. Activated sludge systems are the most common suspended growth bioreactors. Other examples include aerated ponds or lagoons, stabilization ponds (using both algae and bacteria), and sequencing batch reactors.
- In **attached growth** reactors, biomass is attached to a solid substrate, such as sand, rock, plastic, activated carbon, or resin. Reactor design is dependent upon the surface area of substrate media available for biomass growth. Examples include trickling filter, rotating biological contactor, fluidized bed, fixed bed, and roughing filter designs.

Alternative Techniques/Enhanced Methods

- Direct addition of powdered activated carbon (PAC) into suspended growth bioreactors can both improve removal efficiency and reduce the likelihood of process upsets by buffering the concentrations of toxic compounds at levels amenable to biodegradation.

Appendix D4: Aerobic Biological Reactors (continued)

Alternative Techniques/Enhanced Methods (continued)

- Microbial augmentation (the addition of specially cultured microorganisms) may be used to increase the system's removal efficiency for certain difficult-to-degrade contaminants.
- Anaerobic reactors (digesters) may be preferred for the treatment of certain ground-water contaminants (e.g., certain chlorinated organics) that are difficult to degrade aerobically. **However, anaerobic reactors have not been identified as a presumptive technology for the following reasons:** 1) anaerobic processes have not been widely used for ground-water treatment; 2) reaction rates are slower than for aerobic processes, which result in longer startup times (for acclimation) and longer treatment times; and 3) such reactors have a greater sensitivity to process upsets, especially where flow and contaminant concentrations vary over time. These factors generally result in higher operation and maintenance requirements and costs, and lower performance efficiencies than for aerobic processes in ground-water applications.

Pre/Post-treatment

- Chemical precipitation (for metals) or other pretreatment (e.g., PAC addition for organics) may be required to reduce (or buffer) concentrations of compounds that are toxic to microorganisms.
- Carbon adsorption post-treatment may be used to reduce contaminant concentrations in the treated water to meet discharge requirements.
- Because certain aerated bioreactor designs (e.g., mechanically aerated activated sludge systems, aerated ponds and lagoons) present difficulties for direct capture and control of air emissions, an air stripper (with emission controls) may be a cost-effective treatment prior to biodegradation if volatile contaminant emissions need to be controlled. For other bioreactor designs, such as diffused-aeration activated sludge and trickling filter systems, air emissions are more easily captured and can be treated using carbon adsorption, catalytic oxidation, or incineration.

Selected References

- Eckenfelder, W.W., J. Patoczka, and A.T. Watkins. 1985. Wastewater treatment. *Chemical Engineering*: 60-74.
- Fiatman, P.E., D.E. Jerger, and L.S. Bottomley. 1989. Remediation of contaminated groundwater using biological techniques. *Ground Water Monitoring Review*: 105-119.
- U.S. Environmental Protection Agency. 1979. *Selected Biodegradation Techniques for Treatment and/or Ultimate Disposal of Organic Materials*. EPA-600/2-79-006. Office of Research and Development, Cincinnati, OH.
- U.S. Environmental Protection Agency. 1981. *Literature Study of the Biodegradability of Chemicals in Water (Volume 1. Biodegradability Prediction, Advances in and Chemical Interferences with Wastewater Treatment)*. EPA/R806699-01. Office of Research and Development, Cincinnati, OH.
- U.S. Environmental Protection Agency. 1992. *Engineering Bulletin: Rotating Biological Contactors*. EPA/540/S-92/007. Office of Research and Development, Cincinnati, OH. 8 pp.

Appendix D5: Chemical Precipitation

Chemical precipitation chemically converts dissolved metal and/or other inorganic ions in ground water into an insoluble form, or precipitate. Metal ions generally precipitate out as hydroxides, sulfides, or carbonates and are removed as solids through clarification and filtration. In this guidance, chemical precipitation is defined to include chemical precipitation of metals by oxidizing or reducing agents, as well as any pH adjustment (neutralization) and solids removal steps required.

Applicability

Chemical precipitation is *applicable* to dissolved metal and other inorganic ions (such as arsenate and phosphate). Chemical precipitation is *not applicable* to volatile or semivolatile organic compounds (U.S. Navy, 1993).

Contaminant Fate

Dissolved metals are converted to insoluble forms, which are subsequently removed by flocculation, clarification, and/or filtration. The solid residue (chemical sludge) containing the metal contaminant then must be treated and/or disposed of properly.

Design

The process generally takes place at ambient temperatures. Batch reactors are generally favored for lower flowrates (e.g., up to about 50,000 gpd), and usually use two tanks operating in parallel. Each tank can act as a flow equalizer, reactor, and settler, thus eliminating separate equipment for these steps. Continuous systems have a chemical feeder, flash mixer, flocculator, settling unit, filtration system (if used), and control system for feed regulation. Site-specific treatability tests are required to determine the optimum type and dosage of precipitation chemicals, necessary pretreatment steps, and post-treatment requirements for aqueous effluent and sludge residuals.

There are three types of precipitation chemicals:

- **Metal hydroxides** are formed by the addition of alkaline reagents (lime or sodium hydroxide). Precipitation is then initiated by adjusting pH to the optimum level for the particular metal ion. Maintaining pH levels within a relatively narrow optimum range is usually necessary to achieve adequate metal precipitation. Pretreatment with oxidizing or reducing chemicals (e.g., hydrogen peroxide, ferrous sulfate) may be necessary to precipitate some metals (e.g., iron, manganese, chromium) in their least soluble form. Natural organic matter can inhibit the formation of insoluble metal hydroxides by forming metal-organic complexes. Metal hydroxide precipitation is typically effective for arsenic, cadmium, chromium (+3), nickel, zinc, manganese, copper (+2), tin (+3), and iron (+3).
- **Metal sulfides** are formed by the addition of either soluble sulfides (e.g., hydrogen sulfide, sodium sulfide, or sodium bisulfide) insoluble sulfides (e.g., ferrous sulfide). Sodium sulfide and sodium bisulfide are most commonly used. Sulfur dioxide and sulfur metabisulfite have also been demonstrated for chromium reduction prior to precipitation. Metal sulfides have lower solubilities than metal hydroxides, and effective metal removal efficiencies can be achieved over a broader pH range. The method is mainly used to remove mercury and lead and may be used to remove arsenic, cadmium, chromium (+3, or +6), silver and others. Sulfide precipitation also can be used to treat filtered ground water after hydroxide precipitation.

Appendix D5: Chemical Precipitation (continued)

Alternative Techniques/Enhanced Methods

- **Metal carbonates** are formed by the addition of calcium carbonate or by adding carbon dioxide to metal hydroxides. Solubilities of metal carbonates are intermediate between the solubilities of metal hydroxides and metal sulfides. Insoluble metal carbonates are easily filtered from treated ground water. The method is particularly good for precipitating lead, cadmium, and antimony.
- Sodium xanthate has shown promise as a precipitation agent similar to sodium sulfide.

Pre/Post-treatment

- Pretreatment to adjust pH is normally required to obtain the lowest precipitate solubility.
- Pretreatment may be necessary to oxidize iron or manganese compounds or reduce hexavalent chromium compounds into forms that can be readily precipitated.
- Depending on discharge requirements, the aqueous effluent may need pH adjustment and/or further polishing. Activated alumina or ion exchange media are regenerable treatment options for effluent polishing for metals. Activated carbon also may be used but spent carbon may require treatment and disposal as a hazardous waste.
- The sludge may require stabilization treatment by addition of lime/fly ash or portland cement to reduce permeability and the leachability of metals prior to disposal. In some cases, metals may be recovered from the residue for reuse, but this is generally not economical.

Selected References

Monopoli, A.V. 1993. Removing dissolved inorganics from industrial wastewater. *The National Environmental Journal*: 52-56.

U.S. Environmental Protection Agency. 1987. *Handbook on Treatment of Hazardous Waste Leachate*. EPA/600/8-87/006. Office of Research and Development, Cincinnati, OH. pp. 44-45.

U.S. Environmental Protection Agency. 1990. *CERCLA Site Discharges to POTWs Treatability Manual*. EPA/540/2-90/008. Office of Emergency and Remedial Response. PB91-921269/CCE. NTIS, Springfield, VA. pp. 11-23 to 11-36.

U.S. Navy. 1993. *Precipitation of Metals from Ground Water*. NEESA Document Number 20.2-051.6. Navy Energy and Environment Support Activity. Port Hueneme, CA. 11 pp.

Appendix D6: Ion Exchange/Adsorption

Ion exchange removes metal contaminants from water by passing contaminated ground water through a granular solid or other porous material, usually an impregnated resin, that exchanges sorbed ions (e.g., H^+ , OH^- , Na^+ , Li^+ , CO_3^{2-}) for contaminants dissolved in ground water. The ion exchange media are selected to have sorptive affinity for the ionic forms (cation or anion) of the contaminants being removed. The ion exchange media can therefore be either cationic, anionic, or a mixture of the two. Because ion exchange is a reversible process, resins can be regenerated by backwashing with a regeneration solution (e.g., brine; strong or weak acids or bases). Conventional ion exchange resins are generally too costly for large-scale ground-water treatment and are predominantly used for polishing of aqueous effluents after other treatment processes.

Applicability

Ion exchange is *applicable* to ionic contaminants such as dissolved metals or nitrates. Ion exchange is *not applicable* to non-ionic contaminants such as most organic compounds.

Contaminant Fate

Contaminants are removed from ground water through sorption onto the exchange media. When most of the exchange sites of the media become filled, the exchange media are regenerated by backflushing with a suitable regeneration solution. The concentrated backflush solution must then be disposed of or stripped of its contaminants. Exchange resins can generally be regenerated many times and have a relatively long useful life.

Design

Various resin types are available to tailor systems to discrete ionic mixes. For example, acid exchangers replace cations in water with hydrogen ions and base exchangers replace anions with hydroxide ions. Weak acid and base exchangers are selective for more easily removed ions while strong acid and base exchangers are less selective, removing most ions in the ground water. Generally, ease of cation and anion removal follows an affinity sequence specific to the ions in question. Synthetic resins are available with unique selectivity sequences. The wide variety of resins and other ion exchange media (e.g., activated alumina, biological materials) that are available make the selection of an appropriate exchange media a critical design step. Information on the applicability of specific resins may be obtained from resin manufacturers. In addition, ion exchange resins generally have an optimum pH range for effective metals removal. pH control may be required to achieve maximum removal efficiency from ground water.

A typical ion exchange installation has two fixed beds of resin. While one is in operation, the other is regenerated. Batch, fixed column, and continuous column bed designs can be used. Downflow column designs are generally preferred. Continuous column systems eliminate the need for backwashing but are not commonly used because of the complexity of the resin removal mechanics.

Flow rates up to 7,000 gpm have been reported for ion exchange systems. However, conventional ion exchange is generally cost-effective for ground-water treatment only at low flow rates or low contaminant concentrations. It is therefore primarily used as a polishing step following chemical precipitation or other treatment.

Appendix D6: Ion Exchange/Adsorption (continued)

Alternative Techniques/Enhanced Methods

- Activated alumina is an anionic exchange medium comprised of granulated, dehydrated aluminum hydroxide. Activated alumina is effective for removing fluoride, selenium, chromium (+6), and arsenic ions, which are exchanged for hydroxide ions. Adjustment of pH may be necessary to achieve optimal removal efficiency. The alumina is regenerated with a sodium hydroxide solution.
- Biological materials (e.g., algae, crop residues) have recently shown great promise as an innovative ion exchange media for metals. Biological media are significantly less costly than conventional resins (cents per pound vs. dollars per pound), and may become more commonly used for metals removal from ground water.
- Electrodialysis uses alternately placed cation and anion permeable membranes (made of ion exchange resin) and an electrical potential to separate or concentrate ionic species.
- Activated carbon adsorption can also be used to remove inorganics at low concentrations. **However, activated carbon is not identified as a presumptive technology for removal of metals dissolved extracted ground water.** Spent carbon used for metals removal can be difficult to regenerate and may require treatment and/or disposal as a hazardous waste.

Pre/Post-treatment

- Pretreatment may be required to remove suspended solids at concentrations greater than about 25 mg/L or oil at concentrations greater than about 20 mg/L. Large organic molecules also can clog resin pores and may need to be removed.
- pH adjustment may be necessary to achieve optimal metals removal.
- The backwash regeneration solution must be treated to remove contaminants.
- Post-treatment of spent ion exchange media may be required to recover concentrated contaminants or management as a hazardous waste may be required.

Selected References

- Clifford, D., Subramonian, S., and Sorg, T.J., 1986. "Removing Dissolved Inorganic Contaminants from Water," *Environmental Science and Technology*, Vol. 20, No. 11.
- Nyer, E.K. 1985. *Groundwater Treatment Technologies*. Van Nostrand Reinhold. New York, NY. 187 pp.
- U.S. Environmental Protection Agency. 1990. *CERCLA Site Discharges to POTWs Treatability Manual*. EPA/540/2-90/008. Office of Emergency and Remedial Response. PB91-921269/CCE. NTIS. Springfield, VA. pp. 11-102 to 11-112.

Appendix D7: Electrochemical Methods

Electrochemical processes use direct electrical current applied between two immersed electrodes to drive chemical oxidation-reduction reactions in an aqueous solution. Historically, electrochemical processes have been used to purify crude metals or to recover precious metals from aqueous solutions. Positively charged metal ions are attracted to the negatively charged electrode (the cathode), where they are reduced. The reduced metals typically form a metallic deposit on the cathode. Negatively charged ions are attracted to the positively charged electrode (the anode), where they are oxidized.

For contaminated ground water treatment, electrochemical cells have been used for the reduction (and subsequent precipitation) of hexavalent chromium to trivalent chromium. In this process, consumable iron electrodes are used to produce ferrous ions (Fe^{2+}) at the anode and hydroxide ions (OH^-) at the cathode. An oxidation-reduction reaction then occurs between the ferrous, chromium, and hydroxide ions to produce ferric hydroxide $\text{Fe}(\text{OH})_3$ and chromic hydroxide $\text{Cr}(\text{OH})_3$, which subsequently precipitate from solution.

Applicability

Electrochemical processes are *applicable* to dissolved metals. It is most commonly used in ground water treatment for the reduction and precipitation of hexavalent chromium. The process also may be applicable to removing other heavy metals including arsenic, cadmium, molybdenum, aluminum, zinc, and copper ions. Electrochemical processes have also been used for the oxidation of cyanide wastes (at concentrations up to 10 percent). Electrochemical processes are *not applicable* to organic compounds or asbestos.

Contaminant Fate

Dissolved metals either deposit on the cathode or precipitate from solution. Precipitates form an inorganic sludge that must be treated and/or disposed of, typically in a landfill. Spent acid solution, which is used to periodically remove deposits formed on the electrodes, will also require proper treatment and disposal. Cyanide ions are hydrolyzed at the anode to produce ammonia, urea, and carbon dioxide.

Design

Electrochemical reactors generally operate at ambient temperatures and neutral pHs. Both batch reactors and continuous flow reactors are commercially available. A typical electrochemical cell for hexavalent chromium reduction consists of a tank, consumable iron electrodes, and a direct current electrical supply system. An acid solution is used to periodically clean the iron electrodes, which need to be replaced when they are significantly consumed. Reactor residence times required for treatment depend on the contaminants present as well as the degree of mixing and current density. Reduction of hexavalent chromium generally requires short residence times (approximately 10 seconds), whereas treatment of cyanide compounds requires longer process times.

Pre/Post-treatment

- Pretreatment may be necessary to remove suspended solids.
- Settling or clarification post-treatment may be necessary to remove the precipitated trivalent chromic and ferric hydroxides formed during hexavalent chromium electrochemical reduction.

Appendix D7: Electrochemical Methods (continued)

Pre/Post-treatment (continued)

- The sludge may require stabilization prior to disposal by addition of lime/fly ash or portland cement to reduce permeability and metal leachability. In some cases, metals may be recovered from the plated electrode or precipitated residue, but this is generally not economical for typical ground-water applications.

Selected References

Englund, H.M. and L. F. Mafrica. 1987. *Treatment Technologies for Hazardous Waste*. APCA Reprint Series RS-13. Air Pollution Control Association, Pittsburgh, PA. pp. 43-44.

U.S. Environmental Protection Agency. 1990. *A Compendium of Technologies Used in the Treatment of Hazardous Wastes*. EPA/625/8-87/014. Office of Research and Development. PB91-90-274093. NTIS. Springfield, VA. p. 23.

Appendix D8: Aeration of Background Metals

Aeration (contact with air) removes some metals from water by promoting chemical oxidation and the formation of insoluble hydroxides that precipitate from the water. Aeration for metals removal differs from air stripping in that precipitation rather than volatilization is the desired effect of the technology.

Applicability

Aeration techniques are useful for the removal of limited number of dissolved cations and soluble metal compounds. This method is well suited for the removal of background metals such as iron and manganese which is necessary as part of a selected remedy such as pretreatment to air stripping. Methods of aeration for metals include aeration tanks, aeration basins, or cascade aeration. Aeration methods are usually not sufficient as an independent technology for iron and manganese, but are utilized as a step in the treatment process. Often, the air-water contact in tank and cascade aeration is not enough to obtain high removal efficiencies. Spray basins are limited by area, wind, and ice particle formation (Nyer, 1985).

Contaminant Fate

Dissolved metals are oxidized to insoluble hydroxides which precipitate from solution, and can then be subsequently removed by flocculation, sedimentation, and/or filtration.

Design

The three types of aeration systems:

- Aeration tanks bubble compressed air through a tank of water.
- Cascade aeration occurs when air is made by turbulent flow and agitation.
- Spray or aeration basins use an earthen or concrete basin with a piping grid and spray nozzles that spray the water into the air in very fine droplets.

Related methods include aeration used to remove volatile organic contaminants from water are considered to be a type of air stripping, as discussed in Section 2.1.1. The use of aeration to promote aerobic biological treatment processes is considered to be an element of biological treatment as discussed in Section 2.1.4.

Pre/Post Treatment

- Aeration is often a pretreatment for other remediation technologies, such as air stripping, to remove certain metals.
- Aeration can be followed by other treatments such as flocculation, sedimentation, and/or filtration to remove oxidized metals.

Appendix D8: Aeration of Background Metals

Selected References

Betz. 1962. *Betz Handbook of Industrial Water Conditioning*. Trevese, PA. pp.19-22

Nyer, E.K. 1985. *Groundwater Treatment Technologies*. Van Nostrand Reinhold, New York, NY. 187 pp.

Nyer, E.K. 1993. *Practical Techniques for Groundwater and Soil Remediation*. CRC Press, Inc, Boca Raton, FL. 214 pp.

United States Army Corps of Engineers, Kansas City
Draft Feasibility Study Report
Operable Unit 3: Groundwater
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Appendix D

Middlesex County Utility Authority Temporary Discharge Application



MIDDLESEX COUNTY UTILITIES AUTHORITY

P.O. Box 159, Sayreville, NJ 08872-0159

(732)721-3800 Fax(732)727-2254

TEMPORARY DISCHARGE APPROVAL APPLICATION

Groundwater Remediation Control

___ New ___ Renew ___ Modify TDA No. ___

SECTION 1. APPLICANT/RESPONSIBLE PARTY:

1.1. Company name, mailing address, and telephone number.

Telephone No. _____

1.2. Site Identification

I. Site name: _____

II. Street: _____

III. City: _____

IV. State/Zip Code/County: _____

V. Owner/Operator: _____

VI. Telephone no.: _____

VII. Type of Ownership: ___ Federal ___ State ___ County
___ Municipal ___ Private ___ Unknown

VIII. Site Description: _____

1.3 Person to contact concerning information herein:

Name/Title: _____

Company: _____

Telephone: _____

1.4 Authorized representative for the applicant/responsible party:

Name/Title: _____

Company: _____

Telephone: _____

1.5 Operational status of any facilities at the site:

Open _____ Closed _____ Under Construction _____ Proposed _____

Date began/ended/proposed to begin _____

1.6 Please indicate if the facility employs (past, present) a process in any of the following industrial categories or business activities listed below:

- _____ Aluminum Forming
- _____ Asbestos Manufacturing
- _____ Battery Manufacturing
- _____ Builder's Paper Board and Mills
- _____ Carbon Black Manufacturing
- _____ Cement Manufacturing
- _____ Coil Coating
- _____ Copper Forming
- _____ Dairy Products Processing
- _____ Electrical & Electronic Components
- _____ Electroplating/Metal Finishing
- _____ Explosives Manufacturing
- _____ Feedlots
- _____ Ferroalloy Manufacturing
- _____ Fertilizer Manufacturing
- _____ Food/Edible Products- Specify: _____
- _____ Glass Manufacturing
- _____ Grain Mills Manufacturing
- _____ Gum & Wood Chemicals
- _____ Hospitals
- _____ Industrial Laundries
- _____ Ink Formulating
- _____ Inorganic Chemicals
- _____ Iron & Steel
- _____ Leather Tanning & Finishing
- _____ Meat Processing
- _____ Metal Products & Machinery
- _____ Metal Molding & Casting (Foundries)
- _____ Mining and Processing
- _____ Nonferrous Metals Forming and Metal Powders
- _____ Nonferrous Metals Manufacturing
- _____ Oil and Gas Extraction/Coastal Oil & Gas
- _____ Organic Chemicals, Plastics and Synthetic Fibers
- _____ Paint Formulating
- _____ Paving and Roofing Materials(tars and Asphalts)
- _____ Pesticide Chemicals/Formulating & Packaging
- _____ Petroleum Refining
- _____ Pharmaceutical Manufacturing
- _____ Phosphate Manufacturing

- ___ Photographic Processing
- ___ Plastics Molding and Forming
- ___ Porcelain Enameling
- ___ Pulp, Paper, and Paperboard
- ___ Rubber Manufacturing
- ___ Soap & Detergent Manufacturing
- ___ Steam Electric Power Generating
- ___ Textile Mills
- ___ Timber Products Processing
- ___ Transportation Equipment Cleaning
- ___ Waste Treatment
- ___ Other – explain: _____

SECTION 2. DISCHARGE INFORMATION

- 2.1 Description of project and need for Temporary Discharge Approval.
(Attach additional sheets if necessary)

- 2.2 NJDEP Case Number

Name: _____

Division: _____

Bureau: _____

Address: _____

Telephone: _____

- 2.3 Duration of proposed discharge

___ Days ___ Weeks ___ Months ___ Years

A Temporary Discharge Approval shall have a term of one year, renewable each year upon application to and the approval of the Authority, subject to a maximum life of 5 years. After a Temporary Discharge Approval reaches its maximum life of 5 years, it shall expire and the discharge shall cease, unless the Authority, in its discretion, determines to issue a new Temporary Discharge Approvals.

2.4 Volume of propose discharge

_____ Gallons per minute

_____ Gallons per day

_____ Total gallons for duration of project maximum of one year.

2.5 Pretreatment of proposed discharge

_____ Air Flotation

_____ Biological Treatment, type _____

_____ Centrifuge

_____ Chemical Precipitation

_____ Chlorination

_____ Cyclone

_____ Filtration

_____ Flow Equalization

_____ Grease Trap

_____ Grit Removal

_____ Ion Exchange

_____ Neutralization, pH Correction

_____ Oil or Grease Separation, type _____

_____ Ozonation

_____ Rainwater Diversion or Storage _____

_____ Reverse Osmosis

_____ Screen

_____ Sedimentation

_____ Septic Tank

_____ Solvent Separation

_____ Spill Prevention

_____ Sump

_____ Other, explain _____

_____ No Pretreatment Provided

SECTION 3. PROPOSED DISCHARGE CONSTITUENT CONCENTRATIONS

Please indicate by placing an "x" in the appropriate box by each listed chemical whether it is "Believed Absent", or "Believed Present" in the proposed discharge. If the effluent concentration is known or can be estimated, please fill in the appropriate space next to the chemical. If any analyses have been performed on the proposed discharge attach a copy of the most recent data to this application. Be sure to include the date of the analysis, name of the laboratory performing the analysis, location(s) from which sample(s) were taken (attach sketches, plans, etc., as necessary), type of sample taken (e.g. composite, grab), and chain of custody form. Please indicate which concentration measurements are estimated with an E, and explain estimation process.

3.1A USEPA PRIORITY POLLUTANT

Chemical Compound	Believed Absent	Believed Present	Known or Suspected Conc. (mg/L)
Acenaphthene	[]	[]	[]
Acrolein	[]	[]	[]
Acrylonitrile	[]	[]	[]
Benzene	[]	[]	[]
Benzidine	[]	[]	[]
Carbon tetrachloride	[]	[]	[]
Chlorobenzene	[]	[]	[]
1,2,4-Trichlorobenzene	[]	[]	[]
Hexachlorobenzene	[]	[]	[]
1,2-Dichloroethane	[]	[]	[]
1,1,1-Trichloroethane	[]	[]	[]
Hexachlorobenzene	[]	[]	[]
1,1,2-Trichloroethane	[]	[]	[]
1,1,2,2-Tetrachloroethane	[]	[]	[]
Chloroethane	[]	[]	[]
Bis(chloromethyl)ether	[]	[]	[]
Bis(2-chloroethyl)ether	[]	[]	[]
2-Chloroethyl vinyl ether	[]	[]	[]
2-Chloronaphthalene	[]	[]	[]
2,4,6-Trichlorophenol	[]	[]	[]
p-Chloro-m-cresol	[]	[]	[]
Chloroform	[]	[]	[]
2-Chlorophenol	[]	[]	[]
1,2-Dichlorobenzene	[]	[]	[]
1,3-Dichlorobenzene	[]	[]	[]
1,4-Dichlorobenzene	[]	[]	[]
3,3-Dichlorobenzidine	[]	[]	[]
1,1-Dichloroethylene	[]	[]	[]
1,2-Trans-Dichloroethylene	[]	[]	[]
2,4-Dichlorophenol	[]	[]	[]
1,2-Dichloropropane	[]	[]	[]
1,3-Dichloropropylene	[]	[]	[]
(1,3-dichloropropene)	[]	[]	[]
2,4-Dimethylphenol	[]	[]	[]
2,4-Dinitrotoluene	[]	[]	[]
2,6-Dinitrotoluene	[]	[]	[]
1,2-Diphenylhydrazine	[]	[]	[]
Ethylbenzene	[]	[]	[]
Fluoranthene	[]	[]	[]
4-Chlorophenyl phenyl ether	[]	[]	[]

3.1A USEPA PRIORITY POLLUTANT Continued

Chemical Compound	Believed Absent	Believed Present	Known or Suspected Conc. (mg/L)
4-Bromophenyl phenyl ether	[]	[]	[]
Bis(2-chloroisopropyl)ether	[]	[]	[]
Bis(2-chloroethoxy)methane	[]	[]	[]
Methylene chloride	[]	[]	[]
Methyl chloride (Chloromethane)	[]	[]	[]
Methyl bromide (Bromomethane)	[]	[]	[]
Bromoform	[]	[]	[]
Dichlorobromomethane	[]	[]	[]
Chlorodibromoethane	[]	[]	[]
Hexachlorobutadiene	[]	[]	[]
Hexachlorocyclopentadiene	[]	[]	[]
Isohprone	[]	[]	[]
Naphthalene	[]	[]	[]
Nitrobenzene	[]	[]	[]
2-Nitrophenol	[]	[]	[]
4-Nitrophenol	[]	[]	[]
4,6-Dinitro-o-cresol	[]	[]	[]
N-nitrosodimethylamine	[]	[]	[]
N-nitrosodiphenylamine	[]	[]	[]
N-nitrosodi-n-propylamine	[]	[]	[]
Pentachlorophenol	[]	[]	[]
Phenol	[]	[]	[]
Bis(2-ethylhexyl)phthalate	[]	[]	[]
Butyl benzyl phthalate	[]	[]	[]
Di-n-butyl phthalate	[]	[]	[]
Di-n-octyl phthalate	[]	[]	[]
Diethyl phthalate	[]	[]	[]
Dimethyl phthalate	[]	[]	[]
Benzo(a)anthracene	[]	[]	[]
Benzo(a)pyrene	[]	[]	[]
3,4,-Benzofluoranthene	[]	[]	[]
Benzo(k)fluoranthene	[]	[]	[]
Chrysene	[]	[]	[]
Acenaphthylene	[]	[]	[]
Anthracene	[]	[]	[]
Benzo(ghi)perylene	[]	[]	[]
Fluorene	[]	[]	[]
Phenanthrene	[]	[]	[]
Dibenzo(a,h)anthracene	[]	[]	[]

3.4A USEPA PRIORITY POLLUTANT Continued

Chemical Compound	Believed Absent	Believed Present	Known or Suspected Conc. (mg/L)
Indeno(1,2,3-cd)pyrene	[]	[]	[]
Pyrene	[]	[]	[]
Tetrachloroethylene			
(Perchlor)	[]	[]	[]
Toluene	[]	[]	[]
Trichloroethylene			
(Trichloroethene)	[]	[]	[]
Vinyl chloride	[]	[]	[]
Aldrin	[]	[]	[]
alpha-BHC	[]	[]	[]
beta-BHC	[]	[]	[]
gamma-BHC (Lindane)	[]	[]	[]
delta-BHC	[]	[]	[]
4,4-DDT	[]	[]	[]
4,4-DDE	[]	[]	[]
4,4-DDD	[]	[]	[]
Chlordane	[]	[]	[]
Dieldrin	[]	[]	[]
Endosulfan I	[]	[]	[]
Endosulfan II	[]	[]	[]
Endosulfan sulfate	[]	[]	[]
Endrin	[]	[]	[]
Endrin aldehyde	[]	[]	[]
Heptachlor epoxide	[]	[]	[]
Toxaphene	[]	[]	[]
PCB-1016	[]	[]	[]
PCB-1221	[]	[]	[]
PCB-1232	[]	[]	[]
PCB-1242	[]	[]	[]
PCB-1248	[]	[]	[]
PCB-1254	[]	[]	[]
PCB-1260	[]	[]	[]
Antimony(total)	[]	[]	[]
Arsenic(total)	[]	[]	[]
Beryllium(total)	[]	[]	[]
Cadmium(total)	[]	[]	[]
Chromium(total)	[]	[]	[]
Copper(total)	[]	[]	[]
Cyanide(total)	[]	[]	[]
Lead(total)	[]	[]	[]
Mercury(total)	[]	[]	[]

3.4A USEPA PRIORITY POLLUTANT Continued

<u>Chemical Compound</u>	<u>Believed Absent</u>	<u>Known or Believed Present</u>	<u>Suspected Conc. (mg/L)</u>
Nickel(total)	[]	[]	[]
Selenium(total)	[]	[]	[]
Silver(total)	[]	[]	[]
Thallium(total)	[]	[]	[]
Zinc(total)	[]	[]	[]
2,3,7,8-tetrachloro- dibenzo-p-dioxin	[]	[]	[]

3.4B NJDEPE EXPANDED PRIORITY POLLUTANTS Continued

<u>Chemical Compound</u>	<u>Believed Absent</u>	<u>Believed Present</u>	<u>Known or Suspected Conc. (mg/L)</u>
Acrylamide	[]	[]	[]
Amitrole	[]	[]	[]
Amyl alcohols	[]	[]	[]
Aniline hydrochloride	[]	[]	[]
Anisole	[]	[]	[]
Auramine	[]	[]	[]
Benzotrichloride	[]	[]	[]
Benzylamine	[]	[]	[]
o-Chloroaniline	[]	[]	[]
m-Chloroaniline	[]	[]	[]
p-Chloroaniline	[]	[]	[]
1-Chloro-2-nitrobenzene	[]	[]	[]
1-Chloro-4-nitrobenzene	[]	[]	[]
Chloroprene	[]	[]	[]
Chrysoidine	[]	[]	[]
Cumene	[]	[]	[]
2,3-Dichloroaniline	[]	[]	[]
2,4- Dichloroaniline	[]	[]	[]
2,5- Dichloroaniline	[]	[]	[]
3,4- Dichloroaniline	[]	[]	[]
3,5-Dichloroaniline	[]	[]	[]
1,3-Dichloropropene	[]	[]	[]
1,3'-Dimethoxybenzidine	[]	[]	[]
n,n-Dimethyl aniline	[]	[]	[]
3,3'-Dimethyl benzidine	[]	[]	[]
1,1-Dimethylhydrazine	[]	[]	[]
Dioxane	[]	[]	[]
Diphenylamine	[]	[]	[]
Ethylenimine	[]	[]	[]
Hydrazine	[]	[]	[]
4,4'-Methyene bis (2-Chloroaniline)	[]	[]	[]
4,4'-Methylenedianiline	[]	[]	[]
Methyl isobutyl ketone	[]	[]	[]
alpha-Naphthylamine	[]	[]	[]
beta-Naphthylamine	[]	[]	[]
n-Methylaniline	[]	[]	[]
1,2-Phenylenediamine	[]	[]	[]
1,3-Phenylenediamine	[]	[]	[]
1,4-Phenylenediamine	[]	[]	[]

3.4B NJDEPE EXPANDED PRIORITY POLLUTANTS Continued

<u>Chemical Compound</u>	<u>Believed Absent</u>	<u>Believed Present</u>	<u>Known or Suspected Conc. (mg/L)</u>
Sudan I (Solvent yellow 14)	[]	[]	[]
Thiourea	[]	[]	[]
Toluene sulfonic acids	[]	[]	[]
Toluidines	[]	[]	[]
Xylidines	[]	[]	[]

3.4C USEPA HAZARDOUS SUBSTANCES

Chemical Compound	Believed Absent	Believed Present	Known or Suspected Conc. (mg/L)
Acetaldehyde	[]	[]	[]
Allyl alcohol	[]	[]	[]
Allyl chloride	[]	[]	[]
Amyl acetate	[]	[]	[]
Aniline	[]	[]	[]
Benzonitrile	[]	[]	[]
Benzyl chloride	[]	[]	[]
Butyl acetate	[]	[]	[]
Butylamine	[]	[]	[]
Captan	[]	[]	[]
Carbaryl	[]	[]	[]
Carbofuran	[]	[]	[]
Carbon disulfide	[]	[]	[]
Chlorpyrifos	[]	[]	[]
Coumaphos	[]	[]	[]
Cresol	[]	[]	[]
Crotonaldehyde	[]	[]	[]
Cyclohexane	[]	[]	[]
2,4-D (2,4-dichlorophenoxy acetic acid)	[]	[]	[]
Diazinon	[]	[]	[]
Dicamba	[]	[]	[]
Dichlobenil	[]	[]	[]
Dichlone	[]	[]	[]
2,2-Dichloropropionic acid	[]	[]	[]
Dichlorvos	[]	[]	[]
Diethyl amine	[]	[]	[]
Dimethyl amine	[]	[]	[]
Dinitrobenzene	[]	[]	[]
Diguat	[]	[]	[]
Disulfoton	[]	[]	[]
Diuron	[]	[]	[]
Epichlorohydrin	[]	[]	[]
Ethanolaminie	[]	[]	[]
Ethion	[]	[]	[]
Ethylene diamine	[]	[]	[]
Ethylene dibromide	[]	[]	[]
Formaldehyde	[]	[]	[]
Furfural	[]	[]	[]
Guthion	[]	[]	[]
Isoprene	[]	[]	[]

3.4C USEPA HAZARDOUS SUBSTANCES Continued				Known or
Chemical	Believed	Believed		Suspected
<u>Compound</u>	<u>Absent</u>	<u>Present</u>		<u>Conc. (mg/L)</u>
Isopropanolamine	[]	[]	[]	[]
Kelthane	[]	[]	[]	[]
Kepone	[]	[]	[]	[]
Malathion	[]	[]	[]	[]
Mercaptodimethur	[]	[]	[]	[]
Methoxychlor	[]	[]	[]	[]
Methyl mercaptan	[]	[]	[]	[]
Methyl methacrylate	[]	[]	[]	[]
Methyl parathion	[]	[]	[]	[]
Mevinphos	[]	[]	[]	[]
Mexacarbate	[]	[]	[]	[]
Monoethyl aminie	[]	[]	[]	[]
Monomethyl amine	[]	[]	[]	[]
Naled	[]	[]	[]	[]
Napthenic acid	[]	[]	[]	[]
Nitrotoulene	[]	[]	[]	[]
Parathion	[]	[]	[]	[]
Phenosulfanate	[]	[]	[]	[]
Phosgene	[]	[]	[]	[]
Propargite	[]	[]	[]	[]
Propylene oxide	[]	[]	[]	[]
Pyrethrins	[]	[]	[]	[]
Quinoline	[]	[]	[]	[]
Resorcinol	[]	[]	[]	[]
Strontium	[]	[]	[]	[]
Strychnine	[]	[]	[]	[]
Styrene	[]	[]	[]	[]
2,4,5-T (2,4,5-Trichloro- phenoxy acetic acid)	[]	[]	[]	[]
TDE (Tetrachloro- diphenylethane)	[]	[]	[]	[]
2,4,5-TP [2-(2,4,5-Trichloro- phenoxy) propanoic acid]	[]	[]	[]	[]
Trichlorofon	[]	[]	[]	[]
Triethylamine	[]	[]	[]	[]
Trimethylamine	[]	[]	[]	[]
Uranium	[]	[]	[]	[]
Vanadium	[]	[]	[]	[]
Vinyl acetate	[]	[]	[]	[]
Xylene	[]	[]	[]	[]
Xylenol	[]	[]	[]	[]
Zirconium	[]	[]	[]	[]

3.4D MCUA PARAMETERS

<u>Chemical Compound</u>	<u>Believed Absent</u>	<u>Believed Present</u>	<u>Known or Suspected Conc. (mg/L)</u>
Ammonia	[]	[]	[]
Aluminum, Total	[]	[]	[]
Barium, Total	[]	[]	[]
Biological Oxygen Demand	[]	[]	[]
Boron, Total	[]	[]	[]
Bromide	[]	[]	[]
Chemical Oxygen Demand	[]	[]	[]
Chlorine, Total Residual	[]	[]	[]
Cobalt, Total	[]	[]	[]
Color	[]	[]	[]
Fluoride	[]	[]	[]
Iron, Total	[]	[]	[]
Magnesium, Total	[]	[]	[]
Molybendum, Total	[]	[]	[]
Maganese, Total	[]	[]	[]
Nitrate-Nitrite (as N)	[]	[]	[]
Oil & Grease	[]	[]	[]
Petroleum Hydrocarbons	[]	[]	[]
pH(in S.U.)	[]	[]	[]
Phosphorous, Total(as P)	[]	[]	[]
Radioactivity	[]	[]	[]
Sulfate(as SO4)	[]	[]	[]
Sulfide(as S)	[]	[]	[]
Sulfite(as SO3)	[]	[]	[]
Surfactants	[]	[]	[]
Temperature(°C)	[]	[]	[]
Tin, Total	[]	[]	[]
Titanium, Total	[]	[]	[]
TKN(as N)	[]	[]	[]
Total Organic Carbon	[]	[]	[]
Total Dissolved Solids	[]	[]	[]
Total Suspended Solids	[]	[]	[]

SECTION 4. SITE PLAN

Please provide a site plan indicating all activities which make-up the proposed discharge and indicate the proposed connection to the wastewater collection system.

SECTION 5. CERTIFICATION

This is to be signed by an authorized representative of the Applicant/Responsible Party after completion and review of the information in this Temporary Discharge Application.

I have personally examined and am familiar with the information submitted in sections 1, 2, 3, 4 and all attachments. Based upon my inquiry of those individuals immediately responsible for obtaining the information reported herein, I believe that the submitted information is true, accurate and complete, I am aware that there are significant penalties for submitting false information, including the possibility of fine and/or imprisonment.

Signature of Authorized Representative*

Date

Name & Title

Return completed application and all other correspondence to: Middlesex County Utilities Authority, P.O. Box 159, Sayreville, NJ 08872. Attention: Environmental Quality (732)721-3800

*Signatory Requirements For Applicant/Responsible Party

The Temporary Discharge Approval shall be signed as follows:

- (1). By a responsible corporate officer, if the Applicant/Responsible Party is a corporation. For the purpose of this paragraph, a responsible corporate officer means (i) a president, secretary, treasurer, or vice-president of the corporation in charge of a principle business function, or any other person who performs similar policy- or decision-making functions for the corporation, or (ii) the manager of one or more manufacturing, production, or operation facilities employing more than 250 persons or having gross annual sales or expenditures exceeding \$25 million (in second-quarter 1980 dollars), if authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedures.
- (2). By a general partner or proprietor if the Applicant/Responsible Party is a partnership or sole proprietorship respectively.
- (3). By a director or highest official appointed or designated to oversee the operation and performance of the activities of the government facility, if the Applicant/Responsible Party is a Federal, State, or local government facility.
- (4). By a duly authorized representative of the individual designated in paragraph (1) through (3) above if:
 - (i). The authorization is made in writing by the individual described in paragraph (1) through (3);
 - (ii). the authorization specifies either an individual or a position having responsibility for the overall operation of the facility from which the discharge originates, such as the position of plant manager, operator of a well, or well field superintendent, or a position of equivalent responsibility, or having overall responsibility for environmental matters for the company; and
 - (iii). the written authorization is submitted to the Middlesex County Utilities Authority.
- (5). If an authorization under paragraph (4) above is no longer accurate because a different individual or position has responsibility for the overall operation of the facility, or overall responsibility for environmental matters for the company, a new authorization satisfying the requirements of paragraph (4) above must be submitted to the Middlesex County Utilities Authority prior to or together with any reports to be signed by an authorized representative.

EXHIBIT A
MIDDLESEX COUNTY UTILITIES AUTHORITY
DISCHARGE LIMITATIONS
TDA No.

APPLICANT:

EFFECTIVE DATE:

EXPIRATION DATE:

Waste ¹ Characteristics ¹	Daily Maximum	Maximum Monthly Ave.	Monitoring Frequency	Sample Type
Arsenic(Total)	3.000	1.000		Composite
Cadmium(Total)	0.690	0.260		Composite
Chromium(Total)	0.230	0.120		Composite
Chromium (Hexavalent)	0.110	0.060		Composite
Copper(Total)	1.100	0.360		Composite
Lead(Total)	0.600	0.400		Composite
Mercury(Total)	0.110	0.048		Composite
Nickel(Total)	0.360	0.170		Composite
Silver(Total)	0.430	0.240		Composite
Zinc (Total)	2.200	0.660		Composite
Total Toxic Organics ²	2.13	N/L ³		
Volatile Compounds				Grab
Base/Neutral Compounds				Composite
Acid Extractable Compound				Composite
Pentane	Monitoring Only			Grab
TBA	Monitoring Only			
MTBE	Monitoring Only			
PCB'S/Pesticides	BMDL ⁴	BMDL ⁴		Composite
pH (Standard Units)	5.0<Ph <12.5			Grab
Total Petroleum Hydrocarbons	100	N/L ³		Grab
Flow (Total not to exceed)			Continuous	
Flow (Gallons per day)			Continuous	
Flow (Gallons per minute)			Continuous	

¹ All units in mg/l, unless otherwise noted

² Total Toxic Organics are defined in Attachment A

³ N/L No Limitation Established At This Time

⁴ BMDL: Below Minimum Detection Limit

ATTACHMENT A

TOTAL TOXIC ORGANICS

The Term "TTO" shall mean Total Toxic Organics, which is the summation of all quantifiable values greater than 0.01 milligram liter (10 ppb) for the following toxic Organics:

Base/Neutral

Acenaphthene
Acenaphthylene
Anthracene
Benzidine
Benzo (a) anthracene
Benzo (a) pyrene
Benzo (ghi) perylene
Benzo (k) fluoranthene
3,4, -Benzofluoranthene
Bis (2-chloroethoxy) methane
Bis (2-chloroethyl) ether
Bis (2-chloroisopropyl) ether
Bis (2-ethylhexyl) phthalate
4-Bromophenyl phenyl ether
Butyl benzyl phthalate
2-Chloronaphthalene
4-Chorophenyl phenyl ether
Chrysene
Di-n-butyl phthalate
Di-n-octyl phthalate
Dibenzo (a, h) anthracene
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
1,2,4-Trichlorobenzene
Diethyl phthalate
Dimethyl phthalate
2,4-Dinitrotoluene
2,6-Dinitrotoluene
1,2-Diphenylhydrazine
Fluoranthene
Fluorene
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachloroethane
Indeno (1,2,3-cd) pyrene
Isophorone
Naphthalene
Nitrobenzene
N-nitrosodi-n-propylamine
N-nitrosodimethylamine
N-nitrosodiphenylamine
Phenanthrene
Pyrene
3,3-dichlorobenzidine
2,3,7,8-tetrachloro-dibenzo-p-dioxin

Acid Extractable

2-Chlorophenol
2,4-Dichlorophenol
2,4-Dimethylphenol
4,6-Dinitro-o-cresol
2,4-Dinitrophenol
2-Nitrophenol
4-Nitrophenol
p-Chloro-m-cresol
Pentachlorophenol
Phenol
2,4,6-Trichlorophenol

Pesticides/PCB's

Aldrin
alpha-BHC
beta-BHC
gamma-BHC (Lindane)
delta-BHC
Chlordane
4,4'-DDD
4,4'-DDE
4,4'-DDT
Dieldrin
alpha-Endosulfan
beta-Endosulfan
Endosulfan sulfate
Endrin
Endrin aldehyde
Heptachlor
Heptachlor epoxide
Toxaphene
PCB-1016
PCB-1221
PCB-1232
PCB-1242
PCB-1248
PCB-1254
PCB-1260

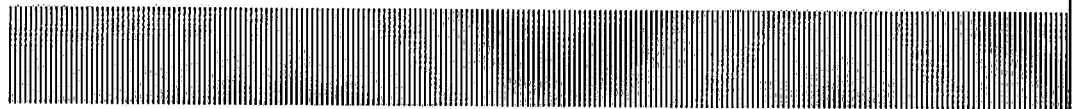
Volatile Organics

Acrolein
Acrylonitrile
Benzene
Bis (chloromethyl) ether
Bromoform (Tribromomethane)
Carbon tetrachloride
Chlorobenzene
Chlorodibromomethane
Chloroethane
2-Chloroethyl vinyl ether
Chloroform (Trichloromethane)
Dichlorobromomethane
Dichlorodifluoromethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethylene
1,2-Dichloropropane
1,3-Dichloropropylene
Ethylbenzene
Methyl bromide (Bromomethane)
Methyl chloride (Chloromethane)
Methylene chloride (Dichloromethane)
1,1,2,2-Tetrachloroethane
Tetrachloroethylene
Toluene
1,2,-trans-Dichloroethylene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethylene
Trichlorofluoromethane
Vinyl Chloride (Chloroethylene)
Xylene

United States Army Corps of Engineers, Kansas City
Draft Feasibility Study Report
Operable Unit 3: Groundwater
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Appendix E

NJAC 7:14A-12: Effluent Standards Applicable to Direct Discharges to Surface Water and Indirect Discharges to Domestic Treatment Works



This is a courtesy copy of this rule. All of the Department's rules are compiled in Title 7 of the New Jersey Administrative Code.

Subchapter 12. Effluent Standards Applicable to Direct Discharges to Surface Water and Indirect Discharges to Domestic Treatment Works

7:14A-12.1 Purpose and Scope

- (a) This subchapter specifies Federal and State effluent standards which may be incorporated into a permit as an effluent limitation for direct discharges to surface water including those discharges conveyed to surface water via storm sewers and indirect discharges to DTWs.
- (b) The effluent standards contained in this subchapter are applicable as follows:
 - 1. Regarding stormwater discharges:
 - i. Any discharge of stormwater authorized by a general permit is exempt from the requirements of this subchapter unless such general permit provides otherwise;
 - ii. Any stormwater discharge shall be subject to one or more requirements of this subchapter when the effluent standard in question is achievable by stormwater treatment processes using commercially available technology and is not achievable using other practicable BMPs, and the fact sheet or statement of basis for the draft permit provides the basis for the inclusion of such requirement(s).
 - 2. Regarding discharges from combined sewer overflows:
 - i. Any discharge from a combined sewer overflow authorized by a general permit is exempt from the requirements of this subchapter unless such general permit provides otherwise;
 - ii. Any discharge from a combined sewer overflow shall be subject to one or more requirements of this subchapter when the fact sheet for the draft permit for such discharge provides the basis for the inclusion of such requirement(s).
 - 3. Any discharge other than those identified at (b)1. above shall be exempt from one or more of the requirements in this subchapter as specified in the applicable section.
 - 4. Any discharge of a parameter to which this subchapter applies that is also regulated by another regulatory agency shall meet the more stringent standards of such agency or of this subchapter.

7:14A-12.2 Secondary Treatment Effluent Standards

- (a) The requirements of this section shall apply to all direct discharges to surface water from publicly or privately owned domestic treatment works included in a NJPDES permit.
- (b) The minimum level of effluent quality attainable by secondary treatment in terms of the parameter BOD₅, except as provided for in N.J.A.C. 7:14A-12.3 is as follows:
 - 1. The monthly average value shall not exceed 30 mg/L;
 - 2. The weekly average value shall not exceed 45 mg/L; and
 - 3. The monthly average value for percent removal shall not be less than 85 percent.
- (c) In lieu of the parameter BOD₅ and the levels of the effluent quality specified in (b) above, the parameter CBOD₅ may be substituted as follows:
 - 1. The monthly average value shall not exceed 25 mg/L;
 - 2. The weekly average value shall not exceed 40 mg/L; and

This is a courtesy copy of this rule. All of the Department's rules are compiled in Title 7 of the New Jersey Administrative Code.

3. The monthly average value for percent removal shall not be less than 85 percent.
- (d) Chemical oxygen demand COD or total organic carbon (TOC) may be substituted for BOD₅ or CBOD₅ when a long-term BOD₅ or CBOD₅:COD or BOD₅ or CBOD₅:TOC correlation is demonstrated whereby a permittee submits data which indicates that a different BOD₅ or CBOD₅:COD or BOD₅ or CBOD₅:TOC ratio would be more appropriate. In the absence of data to establish a long term correlation, the BOD₅:COD ratio shall be assumed to be 1:2 and the BOD₅:TOC ratio shall be assumed to be 1:1.
- (e) The minimum level of effluent quality attainable by secondary treatment in terms of the parameter TSS, except as provided in N.J.A.C. 7:14A-12.3 is as follows:
 1. The monthly average value shall not exceed 30 mg/L;
 2. The weekly average value shall not exceed 45 mg/L; and
 3. The monthly average value for percent removal shall not be less than 85 percent.
- (f) The pH shall be maintained within the limits of 6.0 to 9.0 standard units unless the facility demonstrates that:
 1. Inorganic chemicals are not added to the wastestream as part of the treatment process; and
 2. Contributions from industrial sources do not cause the pH of the effluent to be less than 6.0 or greater than 9.0.

7:14A-12.3 Secondary Treatment Special Considerations

- (a) This section identifies special considerations applicable to effluent limitations for BOD₅ or CBOD₅ and TSS percentage removal or, for facilities receiving waste from certain industrial categories, relief in terms of less stringent BOD₅ or CBOD₅ and TSS concentration levels when the level of treatment required is more stringent than the minimum treatment requirements specified in N.J.A.C. 7:14A-12.2.
- (b) For domestic treatment works receiving less concentrated influent wastewater from combined sewer systems during wet weather, the Department may remove, or impose a less stringent, BOD₅ or CBOD₅ and TSS percent removal requirement than specified in N.J.A.C. 7:14A-12.2(b)3, (c)3 or (e)3. For such treatment works, any attainable percentage removal level shall be defined on a case-by-case basis.
- (c) For domestic treatment works receiving less concentrated influent wastewater from combined sewer systems during dry weather, the Department shall remove, or impose a less stringent, BOD₅ or CBOD₅ and TSS percent removal requirement than specified in N.J.A.C. 7:14A-12.2(b)3, (c)3 or (e)3 if the permittee satisfactorily demonstrates that:
 1. The treatment works is consistently meeting, or will consistently meet its permit effluent concentration limits, but the percent removal requirements cannot be met due to less concentrated influent wastewater. In such case an applicant shall demonstrate compliance with effluent limitations consistently achievable through proper operations and maintenance, as defined in N.J.A.C. 7:14A-1.2; and
 2. To meet the percent removal requirements, the treatment works would have to achieve significantly more stringent effluent limitations, as defined in N.J.A.C. 7:14A-1.2, than would otherwise be required by the concentration-based standards and associated loadings; and
 3. The less concentrated influent wastewater does not result from either excessive infiltration or clear water industrial discharges (for example, non-contact cooling water discharges or other discharges which do not contain pollutants in sufficient quantities to otherwise be of concern) during dry weather periods. If the less concentrated influent wastewater is the result of clear water industrial discharges then the treatment works must control such discharges in accordance with 40 CFR 403.
- (d) For domestic treatment works receiving less concentrated influent wastewater from a separate sewer system, the Department shall remove, or impose a less stringent, BOD₅ or CBOD₅ and TSS percent

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removal requirement than specified in N.J.A.C. 7:14A-12.2(b)3, (c)3 or (e)3, if the permittee satisfactorily demonstrates that:

1. The treatment works is consistently meeting, or will consistently meet, its permit effluent concentration limits but the percent removal requirements cannot be met due to less concentrated influent wastewater. In such case an applicant shall demonstrate compliance with effluent limitations consistently achievable through proper operations and maintenance as defined in N.J.A.C. 7:14A-1.2; and
 2. To meet the percent removal requirements, the treatment works would have to achieve significantly more stringent limitations as defined in N.J.A.C. 7:14A-1.2, than would otherwise be required by the concentration-based standards; and
 3. The less concentrated influent wastewater is not the result of excessive inflow/infiltration.
- (e) For domestic treatment works receiving industrial waste from certain industrial categories, the average monthly values for BOD₅, or CBOD₅ and TSS specified in N.J.A.C. 7:14A-12.2(b)1, (c)1 or (e)1 shall be made less stringent provided that:
1. The permitted discharge of BOD₅ or CBOD₅ and TSS from the domestic treatment works, attributable to the industrial category, would not be greater than that which would be permitted under sections 301(b)(1)(A)(i), 301(b)(2)(E) or 306 of the Federal Act if such industrial category were to discharge directly to surface water; and
 2. The flow or loading for BOD₅ or CBOD₅ and TSS introduced to the domestic treatment works by the industrial category exceeds 10 percent of the design flow or loading of the domestic treatment works. When such an adjustment is made, the weekly average value for BOD₅ or CBOD₅ and TSS specified in N.J.A.C. 7:14A-12.2(b)2, (c)2 or (e)2 shall be adjusted proportionately.
- (f) When requesting special consideration for any of the discharges described in (b), (c) and (d) above, an applicant shall submit, as part of the request, all demonstrations specified in the applicable subsection and, in addition, the following:
1. The BOD₅, or CBOD₅, and TSS percent removal requested, as applicable, and whether the request is for seasonal or year round relief;
 2. If the discharge is also regulated by another regulatory agency (for example, Delaware River Basin Commission, Interstate Environmental Commission), a brief written statement from that regulatory agency that the agency has no objection to the request for special consideration;
 3. At a minimum, 24 consecutive months of influent and effluent data sampled at monthly intervals for BOD₅ or CBOD₅ and TSS concentration, as well as percentage removal, presented in summary form. Pollutant data for BOD₅ or CBOD₅ and TSS shall be sampled in accordance with the methods and procedures described in the applicable permit. Data collected during periods of upsets, bypasses, operational errors or other unusual conditions shall be excluded. The data shall contain, at a minimum, the following information:
 - i. Parameter value in mg/L for influent (concentration only) and effluent (concentration and percent removal);
 - ii. Date on which each sample was taken;
 - iii. Effluent flow at time of each sample;
 - iv. Weather conditions at time of each sampling (for example, raining or dry);
 - v. Total population served; and

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- vi. The total amount of flow attributable to major industrial and commercial users contributing greater than 50,000 gallons per day each.
- 4. All permit limit exceedences;
- 5. For combined sewer systems only, the number of combined sewer overflow points and an estimation, with basis, of what percentage of the total collection system is combined; and
- 6. Any other data that the Department deems appropriate to make an accurate determination on the merits of the request.
- (g) When requesting special consideration for the discharge under (e) above, an applicant shall submit all applicable demonstrations specified in (e) 1 and 2, and, in addition, the following:
 - 1. If the discharge is also regulated by another regulatory agency (for example, Delaware River Basin Commission, Interstate Environmental Commission,), a brief written statement from that regulatory agency that the agency has no objection to the request for special consideration;
 - 2. The adjustment requested; and
 - 3. Any other data that the Department deems appropriate to make an accurate determination on the merits of the request.
- (h) The following domestic treatment works are not eligible to request special consideration under this section:
 - 1. Any domestic treatment works which cannot provide satisfactory demonstrations as required pursuant to (b) through (e) above, as applicable; and
 - 2. Any domestic treatment works subject to the requirements of another regulatory agency (for example, Delaware River Basin Commission, Interstate Environmental Commission) that has not received a written statement from that agency that it has no objection to the request.

7:14A-12.4 Minimum BOD₅ Effluent Standards

- (a) For direct discharges to surface water for which (BOD₅ or CBOD₅) water quality based effluent limitations based upon water quality studies acceptable to the Department have not been developed but are required under N.J.A.C. 7:9B-1.5 or 1.6, the minimum treatment requirements for BOD₅ specified in (b) below shall apply except when more stringent effluent limitations are required by:
 - 1. Section 301 or 306 of the Federal Act;
 - 2. The Delaware River Basin Commission or the Interstate Environmental Commission, as applicable.
- (b) The minimum BOD₅ treatment requirements are as listed in the following table:

WATERSHED TYPE	RECEIVING WATER CLASSIFICATION	BOD ₅ MAXIMUM (MONTHLY/WEEKLY AVG.)	DISCHARGE
Atlantic Coastal Plain	FW2, SE1 SC	15/22.5 mg/L 30/45 mg/l	All Domestic or Domestic combined with industrial
Delaware River Basin	Tributaries Classified as FW2, SE1, SE2 Main stem all zones	25/37.5 mg/L As set forth in the Water Quality Standards for the Delaware River Basin; Resolution 67-7 of the DRBC; April 26, 1967 and subsequent revisions	All All

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Hackensack River Basin	FW2, SE1, SE2, SE3	30/45 mg/L	All
Passaic River Basin (including Newark Bay)	FW2 SE2, SE3	25/37.5 mg/L 30/45 mg/L	All All
Wallkill River Basin	FW2	15/22.5 mg/L	All

(c) In applying the minimum treatment requirements contained in (b) above, the following substitutions may be made:

1. For industrial treatment works, TOC or COD may be substituted for BOD₅ when a long-term BOD₅:COD or BOD₅:TOC correlation has been demonstrated. In the absence of data (to establish a long term correlation), the BOD₅:COD ratio shall be assumed to be 1:2 and the BOD₅:TOC ratio shall be assumed to be 1:1. If subsequent data are submitted which indicate that a different BOD₅:COD or BOD₅:TOC ratio would be more appropriate, a written request shall be submitted to the Department; and
2. For industrial or domestic treatment works, CBOD₅ may be substituted for BOD₅ as follows:
 - i. With prior approval of each regulatory agency with jurisdiction over the discharge, when applicable, if the effluent standard for BOD₅ is 30/45 mg/L, a CBOD₅ effluent standard of 25/40 mg/L, as allowed for in N.J.A.C. 7:14A-12.2(c)1 and 2, may be substituted; or
 - ii. With prior approval of each regulatory agency with jurisdiction over the discharge, when applicable, if the effluent standard for BOD₅ is other than 30/45 mg/L, CBOD₅ may be substituted for BOD₅ when a long term BOD₅:CBOD₅ correlation has been demonstrated. When a request for a substitution of CBOD₅ for BOD₅ is made, the applicant shall submit data demonstrating the appropriate BOD₅:CBOD₅ correlation. The correlation demonstration shall consist of a minimum of 12 BOD₅ and CBOD₅ analyses of split samples obtained at a frequency of twice per month, subject to the following restrictions:
 - (1) For limitations applicable year round, or for limitations applicable during warm weather (for example, May through October), the samples shall be obtained during the months of May through October.
 - (2) For limitations applicable during cold weather (for example, November through April), the samples shall be obtained during the months of November through April.
 - (3) The monthly and weekly BOD₅ effluent limitations shall be recalculated as CBOD₅ monthly and weekly effluent limitations using the approved correlation factor.

(d) Direct discharges to surface water from industrial treatment works shall be exempt from the minimum BOD₅ effluent standards in (b) above, when:

- i. Statistically valid data indicate that the maximum projected BOD₅ concentration is consistently below the applicable effluent standard; or

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- ii. The Department determines that, based on wastewater generating activities, no potential exists for the discharge to add BOD₅, COD or TOC.

7:14A-12.5 Disinfection

- (a) All wastewater that could contain pathogenic organisms such as fecal coliform and/or enterococci organisms shall be subject to continuous year round disinfection prior to discharge into surface waters.
- (b) The State effluent standard for fecal coliform organisms is as follows:
 - 1. The monthly geometric mean shall not exceed 200 colonies/100 mL; and
 - 2. The weekly geometric mean shall not exceed 400 colonies/100 mL.

7:14A-12.6 Foam

- (a) DSW dischargers are prohibited from discharging foam or causing foaming of the receiving water that:
 - 1. Forms objectionable deposits on the receiving water;
 - 2. Forms floating masses producing a nuisance;
 - 3. Produces objectionable color or odor; or
 - 4. Interferes with a designated use of the waterbody.
- (b) Foaming of the receiving waterbody caused by natural conditions shall not be considered a violation of the standard in (a) above.
- (c) For discharges with submerged outfalls, the Department may take into consideration the location, depth and the dispersion characteristics of the discharge in deciding whether or not to include the provisions of (a) above in the permit.

7:14A-12.7 Phosphorus effluent standard

The effluent standard for phosphorus discharged to a freshwater lake, pond or reservoir, or tributaries to these waterbodies is that, at a minimum, no effluent shall contain more than 1.0 mg/l total phosphorus (as P), as a monthly average, unless the discharger(s) to such a waterbody can demonstrate that a less stringent requirement will not result in a violation of the Surface Water Quality Standards (N.J.A.C. 7:9B) or that the control of point sources alone, in the absence of effective nonpoint source controls, will not result in a significant reduction of phosphorus loadings to the waterbody.

7:14A-12.8 Oil and grease effluent standards

- (a) The requirements of N.J.A.C. 7:14A-12.8 through 12.10 apply to direct discharges of oil and grease to surface water, and indirect discharges of petroleum based oil and grease to a domestic treatment works, except as specifically exempted in N.J.A.C. 7:14A-12.10. Indirect users shall comply with any local agency standards for nonpetroleum based oil and grease.
- (b) (Reserved.)
- (c) Direct dischargers to surface waters shall limit the oil and grease effluent content so that such effluent does not:
 - 1. Exhibit a visible sheen;
 - 2. Exceed an average monthly discharge limitation of 10 mg/L; and
 - 3. Exceed a concentration of 15 mg/L in any single sample.
- (d) Indirect users discharging petroleum based oil and grease shall meet the following petroleum hydrocarbon effluent standards except where the control authority has determined that more stringent effluent limitations apply:
 - 1. The average monthly discharge limitation shall not exceed 100 mg/L; and

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2. The concentration in any single sample shall not exceed 150 mg/L.

(e) (Reserved.)

(f) If a direct discharger only discharges petroleum based oil and grease, the Department may specify in the permit that compliance with the oil and grease effluent standards in 12.8(c) above may be monitored using the petroleum hydrocarbons analytical method.

7:14A-12.9 (Reserved.)

7:14A-12.10 Petroleum Hydrocarbon Exemptions

(a) Indirect users shall be exempted from the petroleum hydrocarbon standards specified at N.J.A.C. 7:14A-12.8(d), provided the following requirements are met:

1. The DTW into which the indirect user discharges submits a request for the exemption indicating it meets all of the following criteria:

i. The discharge from the domestic treatment works has met a 10 mg/L average and 15 mg/L maximum limitation for oil and grease for each of the reporting periods during the preceding 12 months, as determined by the Department;

ii. The sludge disposal option currently utilized or planned by the domestic treatment works considers petroleum hydrocarbons a beneficial constituent; and

iii. The DTW shows that the costs for oil and grease removal at its plant are in proportion to the other operation and maintenance costs of the plant.

2. The Department shall have 90 days to review the request for the exemption and make a tentative decision to approve or deny the request. If additional information from the applicant is required, the 90 day period may be extended. The Department shall public notice the tentative decision.

7:14A-12.11 Toxic Effluent Standards

(a) (Reserved.)

(b) (Reserved.)

(c) (Reserved.)

(d) For discharges to surface water from site remediation projects, the chemical specific toxic pollutant effluent standards are set forth in N.J.A.C. 7:14A-12 Appendix B.

(e) For new sources, new discharges or expanded direct discharges to surface water, the chemical specific toxic pollutant effluent standards are set forth in N.J.A.C. 7:14A-12 Appendix C.

7:14A-12 Appendix A (Reserved.)

7:14A-12: Appendix B Effluent Standards for Site Remediation Projects

PARAMETER	EFFLUENT		STANDARDS	
	FW-2 WATERS		SC, SE WATERS	
	monthly average	daily maximum	monthly average	daily maximum
VOLATILE COMPOUNDS				
Acrolein		100		100
Acrylonitrile		50		50
Benzene		7	37	136
Bromoform		8.6	29	58

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Carbon Tetrachloride		6		8.8
Chlorobenzene	15	28	15	28
Chlorodibromomethane		8.2		14
Chloroethane	104	268	104	268
Chloroform		11.4	21	46
Dichlorobromomethane		5		12
1,1-Dichloroethane	22	59	22	59
1,2-Dichloroethane		3	68	211
1,1-Dichloroethylene		6	16	25
1,2-Dichloropropane	153	230	153	230
1,3-Dichloropropylene	10	20	29	44
Ethylbenzene	32	108	32	108
Methyl Bromide	20	40	20	40
Methyl Chloride	86	190	86	190
Methylene Chloride		9.4	40	89
1,1,2,2-Tetrachloroethane		10		10
Tetrachloroethylene		16	22	56
Toluene	26	80	26	80
1,2-Trans-Dichloroethylene	21	54	21	54
1,1,1-Trichloroethane	21	54	21	54
1,1,2-Trichloroethane		12	21	54
Trichloroethylene		5.4	21	54
Vinyl Chloride		10	104	268
ACID COMPOUNDS				
2-Chlorophenol	31	98	31	98
2,4-Dichlorophenol	39	112	39	112
2,4-Dimethylphenol	18	36	18	36
4,6-Dinitro-O-Cresol		60	78	277
2,4-Dinitrophenol	71	123	71	123
2-Nitrophenol	41	69	41	69
4-Nitrophenol	72	124	72	124
Pentachlorophenol		30		30
Phenol	15	26	15	26
2,4,6-Trichlorophenol		20		20

all units in ug/L

- 1 -for manufacturers: 10 ug/L daily maximum and 50 ug/L instantaneous maximum
for applicators: 10 ug/L daily maximum and 25 ug/L instantaneous maximum
- 2 - for manufacturers and formulators - discharge prohibited
- 3 - for manufacturers: 1.5 ug/L daily maximum, 7.5 ug/L instantaneous maximum
for formulators: discharge prohibited

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PARAMETER	EFFLUENT		STANDARDS	
	FW-2 WATERS		SC, SE WATERS	
	monthly average	daily maximum	monthly average	daily maximum
BASE NEUTRAL COMPOUNDS				
Anthracene	22	59	22	59
Benzidine		50		50
Benzo (a) Anthracene		10		10
Benzo (a) Pyrene		20		20
Benzo(b)fluoranthene		10		10
Benzo (k) Fluoranthene		20		20
Bis (2-Chloroethyl) Ether		10		10
Bis (2-Chloroisopropyl) Ether	301	757	301	757
Bis (2-Ethylhexyl) Phthalate		36	59	118
Butyl Benzyl Phthalate		24		24
Chrysene		20		20
Dibenzo (a,h) Anthracene		20		20
1,2-Dichlorobenzene	77	163	77	163
1,3-Dichlorobenzene	31	44	31	44
1,4-Dichlorobenzene		28		28
3,3'-Dichlorobenzidine		60		60
Diethyl Phthalate	81	203	81	203
Dimethyl Phthalate	19	47	19	47
Di-N-Butyl Phthalate	27	57	27	57
2,4 Dinitrotoluene		10		18.2
2,6-Dinitrotoluene	255	641	255	641
Fluoranthene	25	68	25	68
Fluorene	22	59	22	59
Hexachlorobenzene		10		10
Hexachlorobutadiene		10	20	49
Hexachlorocyclopentadiene	240	480		1800
Hexachloroethane	19	38	21	54
Indeno (1,2,3-cd) Pyrene		20		20
Isophorone		20		20
Naphthalene	22	59	22	59
Nitrobenzene	17	34	27	68

all units in ug/L

1 - for manufacturers: 10 ug/L daily maximum and 50 ug/L instantaneous maximum
for applicators: 10 ug/L daily maximum and 25 ug/L instantaneous maximum

2 - for manufacturers and formulators - discharge prohibited

3 - for manufacturers: 1.5 ug/L daily maximum, 7.5 ug/L instantaneous maximum
for formulators: discharge prohibited

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N-Nitrosodimethylamine		20		20
N-Nitrosodiphenylamine		20		20
Phenanthrene	22	59	22	59
Pyrene	25	67	25	67
1,2,4-Trichlorobenzene	68	140	68	140

all units in ug/L

- 1 -for maunfacturers: 10 ug/L daily maximum and 50 ug/L instantaneous maximum
for applicators: 10 ug/L daily maximum and 25 ug/L instantaneous maximum
- 2 - for manufacturers and formulators - discharge prohibited
- 3 - for manufacturers: 1.5 ug/L daily maximum, 7.5 ug/L instantaneous maximum
for formulators: discharge prohibited

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PARAMETER	EFFLUENT		STANDARDS	
	FW-2 WATERS		SC, SE WATERS	
	monthly average	daily maximum	monthly average	daily maximum
PESTICIDES				
Aldrin ²		0.04		0.04
Alpha-BHC		0.02		0.02
Beta-BHC	0.137	0.274	0.46	0.92
Gamma-BHC (Lindane)		0.08		0.03
Chlordane		0.2		0.2
4,4'-DDT ²		0.06		0.06
4,4'-DDE ²		0.04		0.04
4,4'-DDD ²		0.04		0.04
Dieldrin ²		0.03		0.03
Alpha-Endosulfan		0.02		0.02
Beta-Endosulfan		0.04		0.04
Endosulfan Sulfate	0.93	1.86	2	4
Endrin ³		0.04		0.04
Endrin Aldehyde	0.76	1.52	0.81	1.62
Heptachlor		0.02		0.02
Heptachlor Epoxide		0.4		0.4
Toxaphene ³		1		1
METALS AND CYANIDE				
Arsenic	50	100	50	100
Cadmium	50	100	50	100
Chromium	50	100	50	100
Copper	50	100	50	100
Iron	1000	2000	1000	2000
Lead	50	100	50	100
Mercury		1		1
Nickel	72	144	50	100
Selenium	50	100	50	100
Silver	25	50	25	50
Zinc	100	200	100	200
Cyanide	100	200	100	200
DIOXIN				

all units in ug/L

- 1 - for manufacturers: 10 ug/L daily maximum and 50 ug/L instantaneous maximum
for applicators: 10 ug/L daily maximum and 25 ug/L instantaneous maximum
- 2 - for manufacturers and formulators - discharge prohibited
- 3 - for manufacturers: 1.5 ug/L daily maximum, 7.5 ug/L instantaneous maximum
for formulators: discharge prohibited

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2,3,7,8-Tetrachlorodibenzo				
-p-Dioxin		0.01		0.01
PCBs²				
PCBs-1242, 1254, 1221,				
1232, 1248, 1260, 1016		0.5		0.5

i

i

all units in ug/L

1 -for manufacturers: 10 ug/L daily maximum and 50 ug/L instantaneous maximum
for applicators: 10 ug/L daily maximum and 25 ug/L instantaneous maximum

2 - for manufacturers and formulators - discharge prohibited

3 - for manufacturers: 1.5 ug/L daily maximum, 7.5 ug/L instantaneous maximum
for formulators: discharge prohibited

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7:14A-12: Appendix C

Effluent Standards for New Sources, New Discharges or Expanded Direct Discharges

P A R A M E T E R	FACILITY FLOW < 7Q 10 & LARGE TIDAL				FACILITY FLOW > 7Q 10 & SMALL TIDAL			
	FW2 WATERS		SE, SC WATERS		FW2 WATERS		SE, SC WATERS	
	monthly average	daily maximum	monthly average	daily maximum	monthly average	daily maximum	monthly average	daily maximum
VOLATILE COMPOUNDS								
Acrolein		100		100		100		100
Acrylonitrile		50		50		50		50
Benzene		24	37	136		7	37	136
Bromoform	29	58	29	58		8.6	29	58
Carbon Tetrachloride		6	18	38		6		8.8
Chlorobenzene	15	28	15	28	15	28	15	28
Chlorodibromomethane		14		14		8.2		14
Chloroethane	104	268	104	268	104	268	104	268
Chloroform	21	46	21	46		11.4	21	46
Dichlorobromomethane		5.4		12		5		12
1,1-Dichloroethane	22	59	22	59	22	59	22	59
1,2-Dichloroethane		7.6	68	211		3	68	211
1,1-Dichloroethylene	16	11.4	16	25		6	16	25
1,2-Dichloropropane	153	230	153	230	153	230	153	230
1,3-Dichloropropylene	29	44	29	44		20	29	44
Ethylbenzene	32	108	32	108	32	108	32	108
Methyl Bromide	20	40	20	40	20	40	20	40
Methyl Chloride	86	190	86	190	86	190	86	190
Methylene Chloride	40	89	40	89		9.4	40	89
1,1,2,2-Tetrachloroethane		10		10		10		10
Tetrachloroethylene	22	56	22	56		16	22	56
Toluene	26	80	26	80	26	80	26	80
1,2-Trans-Dichloroethylene	21	54	21	54	21	54	21	54
1,1,1-Trichloroethane	21	54	21	54	21	54	21	54
1,1,2-Trichloroethane	21	54	21	54		12	21	54
Trichloroethylene	21	54	21	54		5.4	21	54
Vinyl Chloride	20	40	104	268		10	104	268
ACID COMPOUNDS								
2-Chlorophenol	31	98	31	98	31	98	31	98

all units in ug/L

- 1 -for manufacturers: 10 ug/L daily maximum and 50 ug/L instantaneous maximum
for applicators: 10 ug/L daily maximum and 25 ug/L instantaneous maximum
- 2 - for manufacturers and formulators - discharge prohibited
- 3 - for manufacturers: 0.1 ug/L daily maximum, 0.5 ug/L instantaneous maximum
for formulators: discharge prohibited

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2,4-Dichlorophenol	39	112	39	112	39	112	39	112
2,4-Dimethylphenol	18	36	18	36	18	36	18	36
4,6-Dinitro-O-Cresol	78	277	78	277		60	78	277
2,4-Dinitrophenol	71	123	71	123	71	123	71	123
2-Nitrophenol	41	69	41	69	41	69	41	69
4-Nitrophenol	72	124	72	124	72	124	72	124
Pentachlorophenol		30		30		30		30
Phenol	15	26	15	26	15	26	15	26
2,4,6-Trichlorophenol		42	65	130		20		20

all units in ug/L

1 - for manufacturers: 10 ug/L daily maximum and 50 ug/L instantaneous maximum
for applicators: 10 ug/L daily maximum and 25 ug/L instantaneous maximum

2 - for manufacturers and formulators - discharge prohibited

3 - for manufacturers: 0.1 ug/L daily maximum, 0.5 ug/L instantaneous maximum
for formulators: discharge prohibited

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P A R A M E T E R	FACILITY FLOW < 7Q 10 & LARGE TIDAL				FACILITY FLOW > 7Q 10 & SMALL TIDAL			
	FW2 WATERS		SE, SC WATERS		FW2 WATERS		SE, SC WATERS	
	monthly average	daily maximum	monthly average	daily maximum	monthly average	daily maximum	monthly average	daily maximum
BASE NEUTRAL COMPOUNDS								
Anthracene	22	59	22	59	22	59	22	59
Benzidine ¹		50		50		50		50
Benzo (a) Anthracene		10		10		10		10
Benzo (a) Pyrene		20		20		20		20
Benzo(b)fluoranthene		10		10		10		10
Benzo (k) Fluoranthene		20		20		20		20
Bis (2-Chloroethyl) Ether		10	14	28		10		10
Bis (2-Chloroisopropyl) Ether	301	757	301	757	301	757	301	757
Bis (2-Ethylhexyl) Phthalate	103	279	103	279		36	59	118
Butyl Benzyl Phthalate		24		24		24		24
Chrysene		20		20		20		20
Dibenzo (a,h) Anthracene		20		20		20		20
1,2-Dichlorobenzene	77	163	77	163	77	163	77	163
1,3-Dichlorobenzene	31	44	31	44	31	44	31	44
1,4-Dichlorobenzene		28		28		28		28
3,3'-Dichlorobenzidine		60		60		60		60
Diethyl Phthalate	81	203	81	203	81	203	81	203
Dimethyl Phthalate	19	47	19	47	19	47	19	47
Di-N-Butyl Phthalate	27	57	27	57	27	57	27	57
2,4 Dinitrotoluene		10	91	182		10		18.2
2,6-Dinitrotoluene	255	641	255	641	255	641	255	641
1,2-Diphenylhydrazine	0.4	0.8	5.4	10.8	0.04	0.08	0.54	1.08
(as Azobenzene)								
Fluoranthene	25	68	25	68	25	68	25	68
Fluorene	22	59	22	59	22	59	22	59
Hexachlorobenzene		10		10		10		10
Hexachlorobutadiene	20	49	20	49		10	20	49
Hexachlorocyclopentadiene		1800		1800	240	480		1800
Hexachloroethane	21	54	21	54	19	38	21	54
Indeno (1,2,3-cd) Pyrene		20		20		20		20

all units in ug/L

1 - for manufacturers: 10 ug/L daily maximum and 50 ug/L instantaneous maximum
for applicators: 10 ug/L daily maximum and 25 ug/L instantaneous maximum

2 - for manufacturers and formulators - discharge prohibited

3 - for manufacturers: 0.1 ug/L daily maximum, 0.5 ug/L instantaneous maximum
for formulators: discharge prohibited

This is a courtesy copy of this rule. All of the Department's rules are compiled in Title 7 of the New Jersey Administrative Code.

Isophorone		20		20		20		20
Naphthalene	22	59	22	59	22	59	22	59
Nitrobenzene	27	68	27	68	17	34	27	68
N-Nitrosodimethylamine		20	73	146		20		20
N-Nitrosodiphenylamine		20		20		20		20
Phenanthrene	22	59	22	59	22	59	22	59
Pyrene	25	67	25	67	25	67	25	67
1,2,4-Trichlorobenzene	68	140	68	140	68	140	68	140

all units in ug/L

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for applicators: 10 ug/L daily maximum and 25 ug/L instantaneous maximum
- 2 - for manufacturers and formulators - discharge prohibited
- 3 - for manufacturers: 0.1 ug/L daily maximum, 0.5 ug/L instantaneous maximum
for formulators: discharge prohibited

This is a courtesy copy of this rule. All of the Department's rules are compiled in Title 7 of the New Jersey Administrative Code.

P A R A M E T E R	FACILITY FLOW < 7Q 10 & LARGE TIDAL				FACILITY FLOW > 7Q 10 & SMALL TIDAL			
	FW2 WATERS		SE, SC WATERS		FW2 WATERS		SE, SC WATERS	
	monthly average	daily maximum	monthly average	daily maximum	monthly average	daily maximum	monthly average	daily maximum
PESTICIDES								
Aldrin ²		0.04		0.04		0.04		0.04
Alpha-BHC	0.0391	0.0782	0.131	0.262		0.02		0.026
Beta-BHC	1.4	2.8	4.6	9.2		0.28	0.46	0.92
Gamma-BHC (Lindane)		0.38		0.32		0.037		0.125
Chlordane		0.2		0.2		0.2		0.2
4,4'-DDT ²		0.06		0.06		0.06		0.06
4,4'-DDE ²		0.04		0.04		0.04		0.04
4,4'-DDD ²		0.04		0.04		0.04		0.04
Dieldrin ²		0.03		0.03		0.03		0.03
Alpha-Endosulfan	0.22	0.44		0.068		0.092		0.02
Beta-Endosulfan	0.22	0.44		0.068		0.092		0.02
Endosulfan Sulfate	9.3	18.6	20	40	0.93	1.86	2	4
Endrin ³		0.04		0.04		0.04		0.04
Endrin Aldehyde	7.6	15.2	8.1	16.2		1.52		1.62
Heptachlor		0.02		0.02		0.02		0.02
Heptachlor Epoxide		0.4		0.4		0.4		0.4
Toxaphene ³		1		1		1		1
METALS								
Antimony	140	280				28		
Arsenic		8		8		8		8
Cadmium		4	43	86		4		15.2
Chromium, hexavalent	50	100	50	100	50	100	50	100
Chromium, total		32	409	818		16	41	82
Copper		18.4		10		10		10
Iron	1500	3000	1500	3000	1000	2000	1500	3000
Lead		21	69.5	139		10		13.9
Mercury		1		1		1		1
Nickel	720	1440	67.9	136	72	144		13.6
Selenium	20	40	300	600		10		
Silver		2.4		4.6		2		2
Thallium	17	34	62.2	124.4		10		12.4

all units in ug/L

1 - for manufacturers: 10 ug/L daily maximum and 50 ug/L instantaneous maximum
for applicators: 10 ug/L daily maximum and 25 ug/L instantaneous maximum

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for formulators: discharge prohibited

This is a courtesy copy of this rule. All of the Department's rules are compiled in Title 7 of the New Jersey Administrative Code.

Zinc	65	130	95	190		65	47.5	95
Cyanide		44		40		40		40
Total PCB's ²		0.5		0.5		0.5		0.5
DIOXIN								
2,3,7,8-Tetrachlorodibenzo -p-Dioxin		0.01		0.01		0.01		0.01
WHOLE EFFLUENT								
Chronic IC ₂₅ (% effluent)		>=50		>=50		>=100		>=100

all units in ug/L

- 1 -for manufacturers: 10 ug/L daily maximum and 50 ug/L instantaneous maximum
for applicators: 10 ug/L daily maximum and 25 ug/L instantaneous maximum
- 2 - for manufacturers and formulators - discharge prohibited
- 3 - for manufacturers: 0.1 ug/L daily maximum, 0.5 ug/L instantaneous maximum
for formulators: discharge prohibited

N.J.A.C. 7:14A-12 Appendix C **UNOFFICIAL VERSION**. The Official Version can be obtained from West Publishing, 1-800-808-WEST

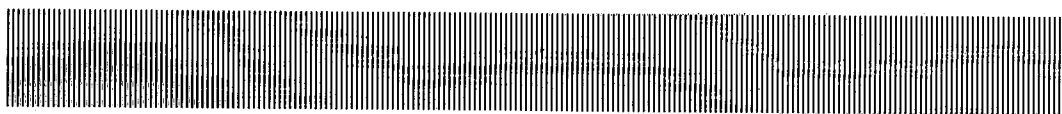
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United States Army Corps of Engineers, Kansas City
Draft Feasibility Study Report
Operable Unit 3: Groundwater
Cornell-Dubilier Electronics Superfund Site
South Plainfield, New Jersey

Appendix F

Source Area Thermal Treatment Estimate from TerraTherm



Summary of Conceptual Design Parameters

and

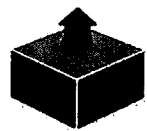
Preliminary Costs for ISTD - SEE Treatment

**Cornell-Dubilier Electronics (CDE)
Superfund Site**

South Plainfield, New Jersey

Prepared for

Malcolm Pirnie/ARCADIS



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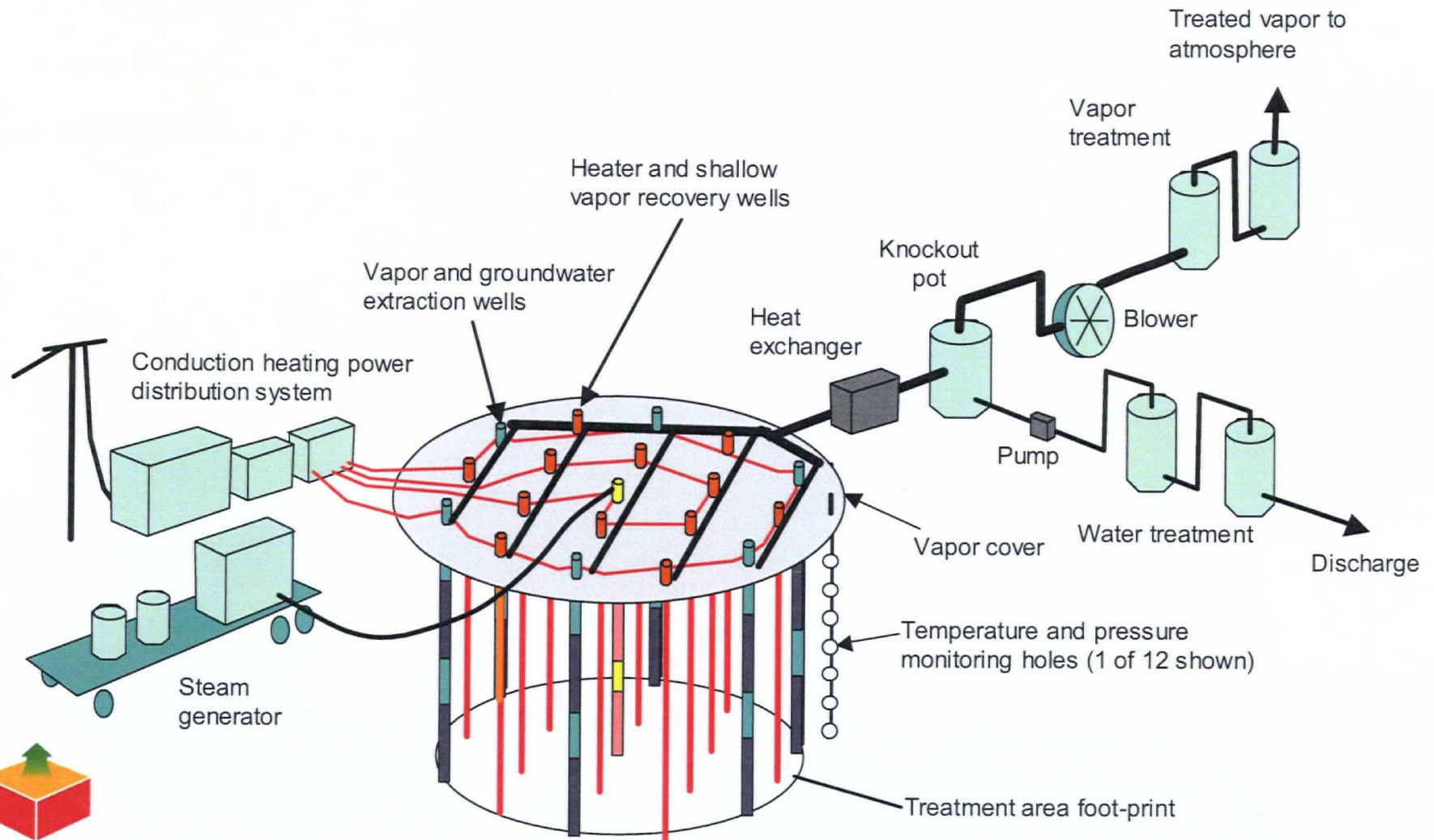
March 23, 2011

Cornell-Dubilier Electronics (CDE) Superfund Site South Plainfield, New Jersey Conceptual Design Summary

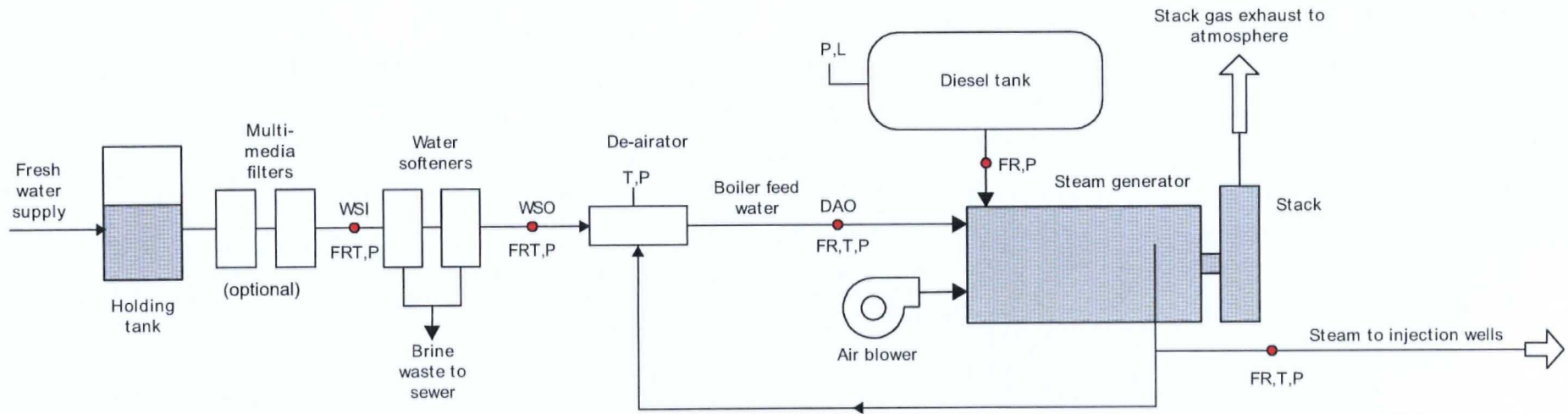
- The site has been designed to include both in-situ thermal desorption (ISTD) in the 0-50 ft bgs and steam enhanced extraction (SEE) in the 50-65 ft bgs vertical.
- This will allow sufficient heating of the zones.
- Thermal Oxidation has been included as a conservative estimate for vapor treatment since the contaminant mass has not been provided.
- Liquid granular activated carbon (GAC) is included for the liquid treatment.



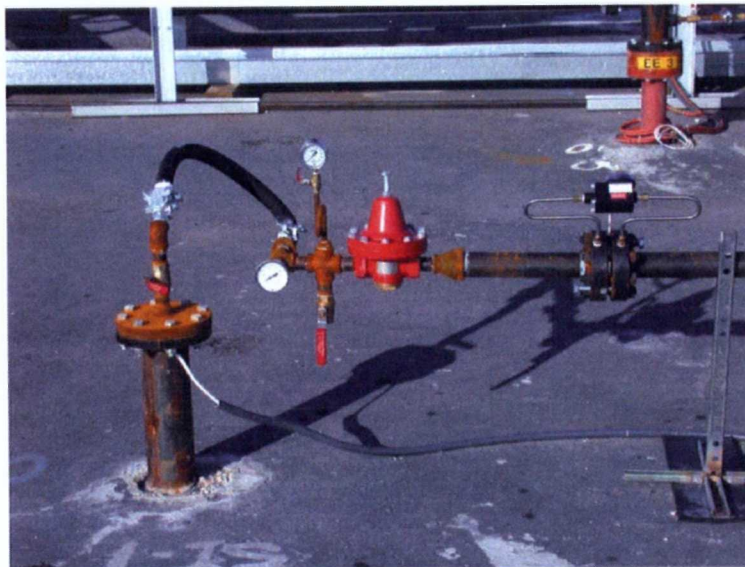
Typical TCH – SEE Layout



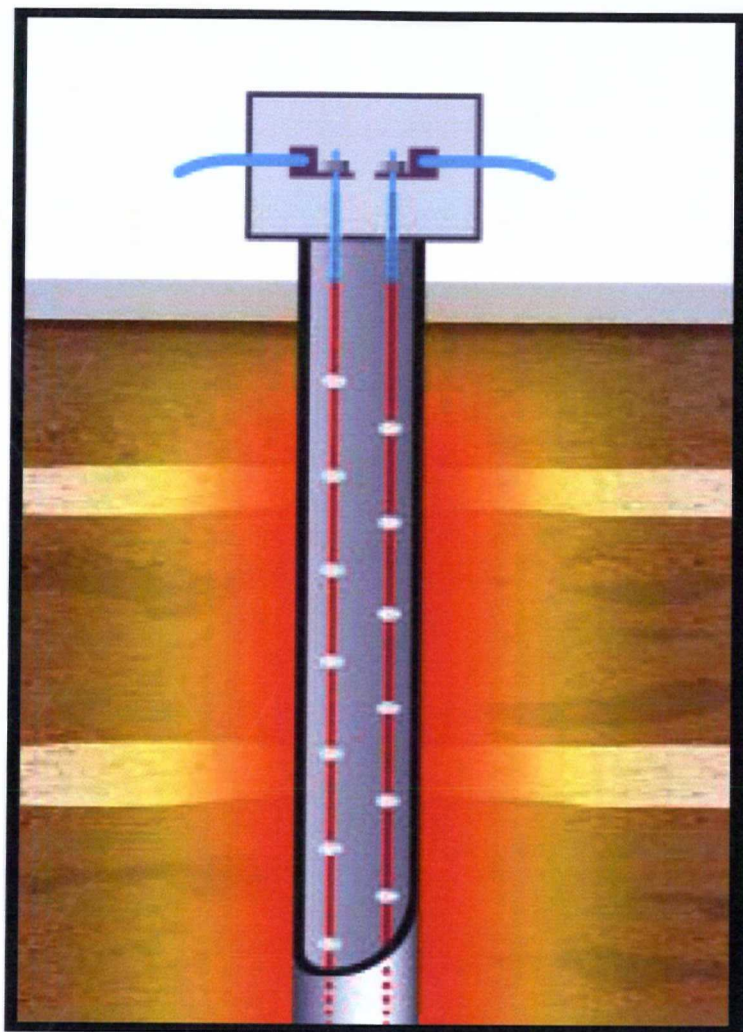
Process equipment, JP-2 fired steam generator



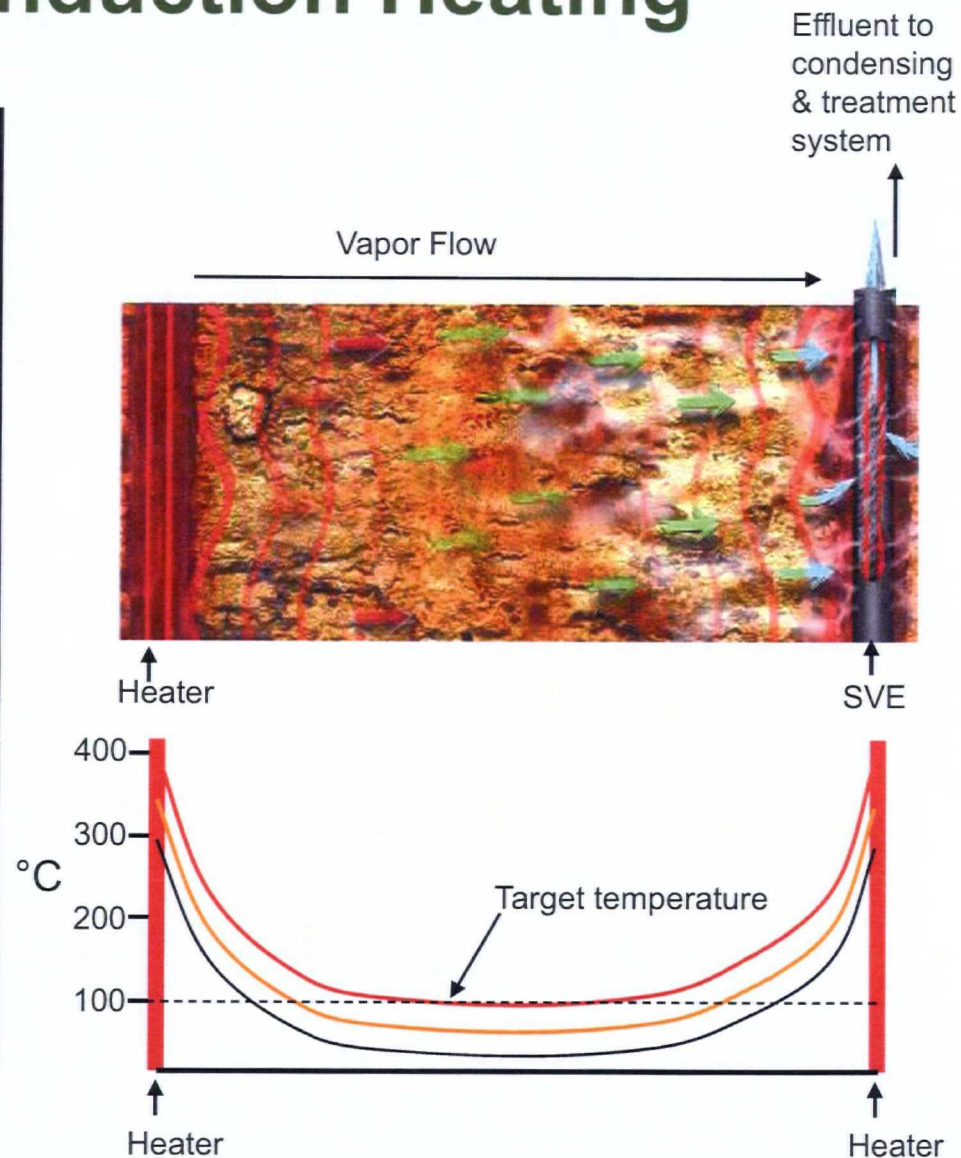
**Typical
steam
injection
well-head
completion**



ISTD - Thermal Conduction Heating

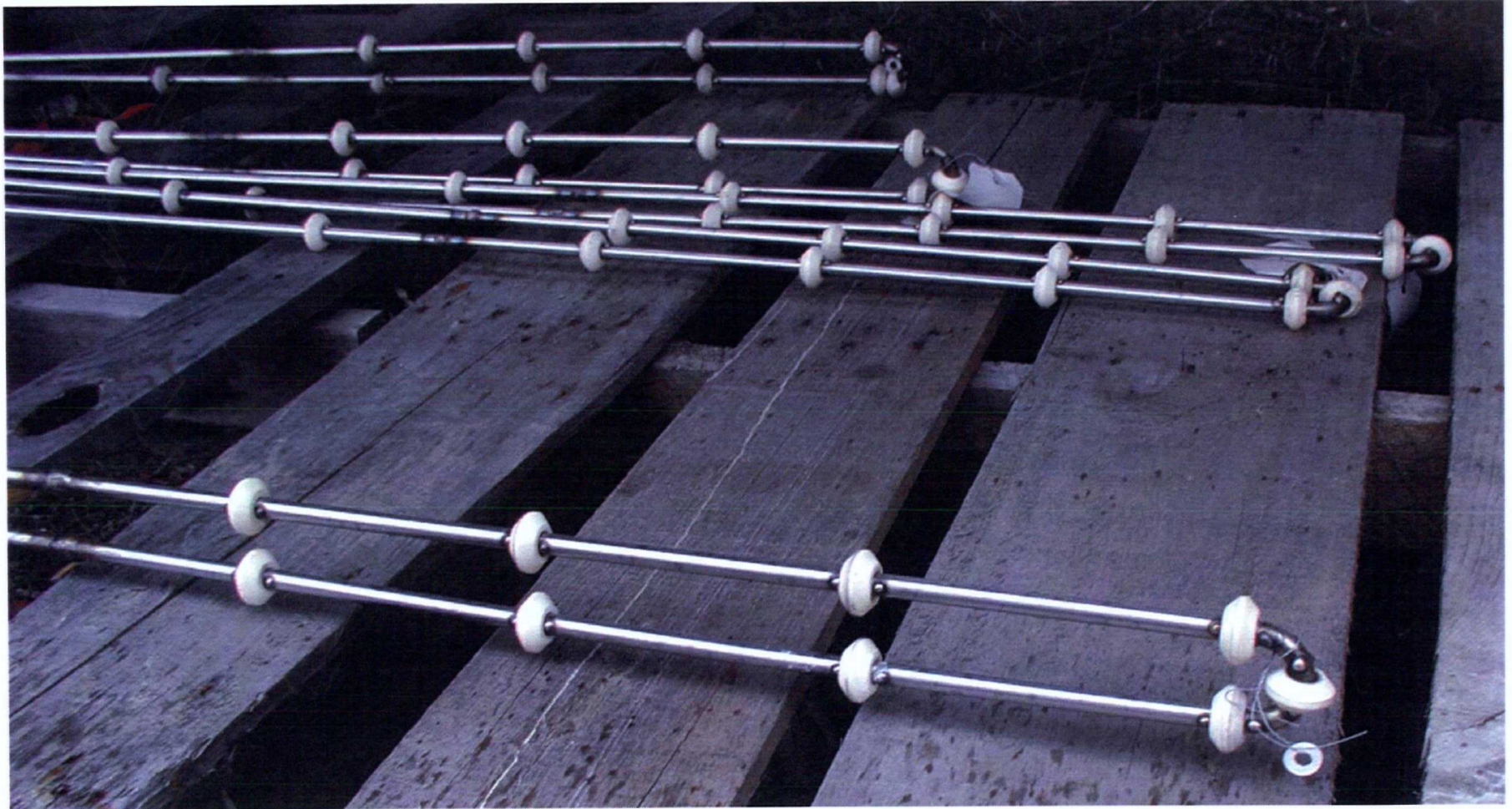


Heater Well Schematic



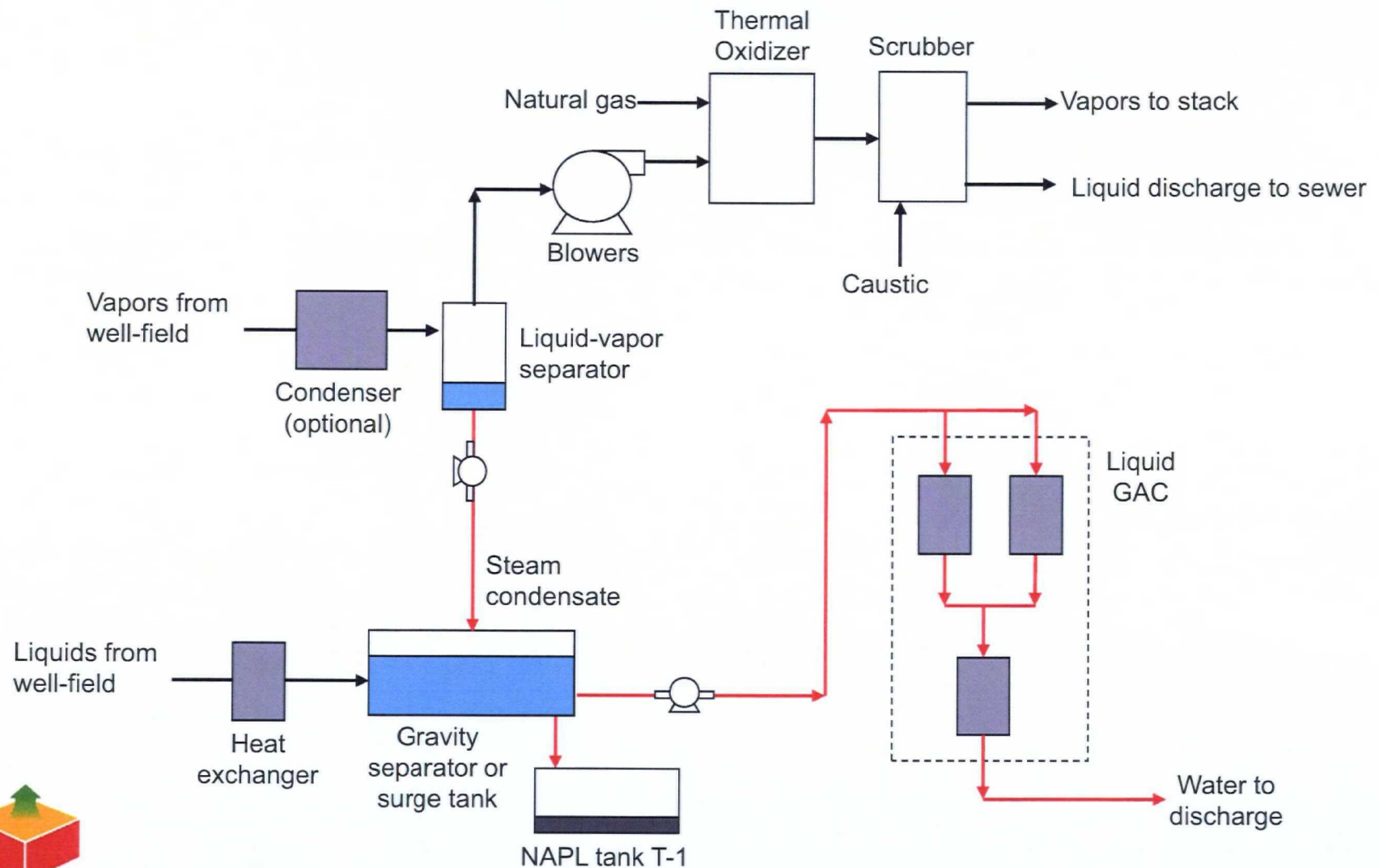
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Thermal Conduction Heaters



U.S. Patent Nos. include 5,190,405, 5,318,116, 6,485,232 and 6,632,047. Protected by International Patents Issued and Pending.

Proposed Effluent Treatment System: Thermal Oxidation Based Vapor Treatment



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Cornell-Dubilier Electronics (CDE) Superfund Site

South Plainfield, New Jersey

Preliminary Design Summary

Cornell-Dubilier Electronics (CDE) Superfund Site				Arcadis
<i>Volume and heat capacity</i>	<i>Zone 1</i>	<i>Zone 2</i>	<i>Total</i>	<i>Unit</i>
Treatment area	44,944	44,944	-	ft ²
Upper depth of treatment	0	50	-	ft bgs
Lower depth of treatment	50	65	-	ft bgs
Volume, TTZ	83,230	24,969	108,199	yd ³
Solids volume	74,907	22,472	97,379	yd ³
Porosity	0.10	0.10	-	-
Porosity volume	8,323	2,497	10,820	yd ³
Initial saturation	70	100	-	percent
Soil weight	334,481,366	100,344,410	434,825,775	lbs soil
Water weight	9,830,677	4,213,147	14,043,824	lbs water
Soil heat capacity	83,620,341	25,086,102	108,706,444	BTU/F
Water heat capacity	9,830,677	4,213,147	14,043,824	BTU/F
Total heat capacity, whole TTZ	93,451,019	29,299,250	122,750,268	BTU/F



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Cornell-Dubilier Electronics (CDE) Superfund Site
South Plainfield, New Jersey
Preliminary Design Summary, continued

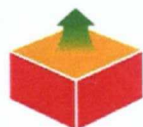
Cornell-Dubilier Electronics (CDE) Superfund Site				Arcadis
Energy balance	Zone 1	Zone 2	Total	Unit
Steam injection rate	-	17,000	17,000	lbs/hr
TCH power input rate	4,220	-	4,220	kW
Water extraction rate during heatup	0.0	78.0	78	gpm
Average extracted water temperature	190	114	-	F
Percent of injected steam extracted as steam	30	10	-	%
Steam extracted, average	4,448	1,700	6,148	lbs/hr
Energy flux into treatment volume	14,395,737	16,507,000	30,902,737	BTU/hr
Energy flux in extracted groundwater	15	2,486,600	2,486,615	BTU/hr
Energy flux in extracted steam	4,318,721	1,650,700	5,969,421	BTU/hr
Net energy flux into treatment volume	10,077,001	12,369,700	22,446,701	BTU/hr
Heating per day	2.6	10.1	-	F/day
Start temperature	50	50	-	F
Target temperature	212	212	-	F
Estimated heat loss, worst case	36	45	-	%
Operating time				
Shake-down	7	7	-	days
Dewatering	0	0	-	days
Heating to boiling point	85	23	-	days
Boiling and drying	29	10	-	days
Heating to target temperature	0	0	-	days
Sampling/analysis phase	10	10	-	days
Post treatment vapor extraction	14	14	-	days
Total operating time	145		-	days



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Cornell-Dubilier Electronics (CDE) Superfund Site
South Plainfield, New Jersey
Preliminary Design Summary, continued

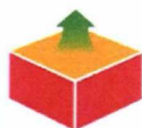
Cornell-Dubilier Electronics (CDE) Superfund Site		Arcadis
Numbers of wells	Zone 1	Zone 2
Heater borings, regular application	279	-
Vertical SVE well, regular application	82	-
Multiphase extraction well, pumping	82	28
Steam injection wells	-	85
Temperature monitoring holes	-	51
Pressure monitoring wells	13	-
Process equipment	Value	Unit
ISTD power supply	4,220	kW
Treatment system power supply	340	kW
Total power need to site	5,700	kW
Estimated transformer size, 480 V	7,100	kVA
Water softener feed rate	34.0	gpm
Steam generator capacity	17,000.0	lbs/hr
Vapor extraction rate, total	4,400	scfm
Non-condensable vapor	2,200	scfm
Estimated steam extraction	2,200	scfm
Liquid extraction rate	78.0	gpm
Condensed liquid rate	12.3	gpm
Water treatment rate	90.3	gpm
Vapor treatment type	Thermox	-
Dominant contaminant of concern	TCE	-
Estimated COC mass	4,000	lbs
Estimated COC mass treated by vapor system	3,600	lbs
Estimated mass generated as NAPL	400	lbs
Estimated maximum mass removal rate	60	lbs/day



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Cornell-Dubilier Electronics (CDE) Superfund Site
South Plainfield, New Jersey
Preliminary Design Summary, continued

Cornell-Dubilier Electronics (CDE) Superfund Site		Arcadis
<i>Utility estimates</i>	<i>Value</i>	<i>Unit</i>
Steam usage, total	9,487,000	lbs
Power usage, total	13,815,000	kWh
Gas usage, total	13,800	MM BTU
Discharge water, total	8,936,000	gallons
Discharge vapor, total	388	mill scf



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Cornell-Dubilier Electronics (CDE) Superfund Site
South Plainfield, New Jersey
Preliminary Cost Estimate

➤ Accurate to
+30 / -20%

Task	Subtask	Price (\$)
Design and preparation	Conceptual design and cost estimate	45,144
	Detailed design, permitting	191,000
	Procurement	170,000
Site activities pre operation	Mobilization and site setup	246,000
	Power drop and transformer	Not included
	Drilling and well installation	3,168,000
	Vapor cover installation	422,000
	Well-field piping	853,000
	ISTD power equipment installation	156,000
	Steam generation system installation	81,000
	Treatment system installation	925,000
	Electrical installation, well-field and process	114,000
	Instrument and monitoring system installation	59,000
	Pre-startup and shakedown	64,000
Operation	ISTD power equipment rental	78,000
	Steam generation system rental	122,000
	Effluent treatment system rental	83,000
	Labor, travel, per diem	240,000
	Process monitoring, sampling and analysis	57,000
	Waste and GAC	1,000
	Repair/maintenance	52,000
	Tools, rentals and fees	19,000
Demob and other	Decommissioning	201,000
	Site Clearance & Demob	118,000
	Reporting	47,000
Indirect costs	Field support	68,000
	Home office support	114,000
	ISTD licensing fees	246,000
	Subtotal without utilities	7,940,000
Utilities, paid by client	Power	1,658,000
	Gas	248,000
	Caustic	2,000
Total		9,848,000



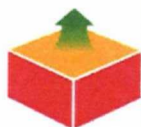
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Cornell-Dubilier Electronics (CDE) Superfund Site

South Plainfield, New Jersey

General Assumptions

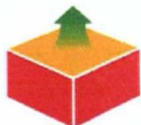
Assumptions	
Cornell-Dubilier Electronics (CDE) Superfund Site	
1	Treatment temperature is 100C using thermal conductive heating (or In-situ thermal desorption - ISTD) for Zone#1 and Steam for Zone#2
2	The treatment address volatile organic compounds only and any other organic compounds that would remediate at 100C
3	Current design does not require the installation of perimeter hydraulic control
4	Basis of contracting is cost plus fixed fee unless otherwise agreed
5	All data provided is considered a good faith representation of the site conditions.
6	24-hr site security is not included
7	This is a turn-key preliminary cost; task sharing can occur and is typically discussed at a later time
8	Power and other utilities are assumed to be available to the site with service available in a reasonable timeframe
9	Permitting fees are excluded; details to apply for permitting are provided
10	Discharge/disposal of treated effluents and any GAC or NAPL produced during operation is excluded
11	Site will be free of any existing infrastructure not compatible with treatment temperatures
12	Any structures existing on site will be accessible as necessary and sufficient space is provided for unencumbered thermal operations
13	The treatment includes two zone: Zone#1 = 0-50 ft bgs and Zone#2 = 50-65 ft bgs
14	The treatment area is approximately 45,000 sf
15	The treatment volume is approximately 108,200 cy
16	The estimated mass totals 4000 lbs
17	The porosity has been included as 0.10 for both zones
18	The initial saturation is estimated to be 70% for Zone#1 and 100% for Zone#2



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Cornell-Dubilier Electronics (CDE) Superfund Site
South Plainfield, New Jersey
General Assumptions, continued

Assumptions	
Cornell-Dubilier Electronics (CDE) Superfund Site	
19	The water table is at 15 ft bgs
20	The estimated hydraulic conductivity is 0.0001 cm/sec
21	The hydraulic gradient for Zone#1 is assumed to be 0.00001 ft/ft and 0.003 ft/ft for Zone#2
22	The groundwater influx from the bottom of Zone#2 is estimated to be 5 gpm
23	It is estimated that 30% of the pore water will be boiled off in treating Zone#1
24	Zone#1 will be treated with Heater wells placed at 15 ft spacing
25	Zone#2 will be treated with Steam wells placed at 30 ft spacing
26	Extraction of contaminants for Zone#1 will include MPE wells at 50ft and SVE wells in the unsaturated 0-15 ft bgs
27	Extraction of contaminants for Zone#2 will include MPE wells at 65ft
28	Zone#1 includes 279 heater wells, 82 vertical SVE wells, and 82 MPE wells
29	Zone#2 includes 85 steam wells and 28 MPE wells
30	51 temperature monitoring holes will be installed over the treatment vertical
31	13 pressure monitoring points will be installed in the 0-15 ft bgs unsaturated zone
32	Vapor cap will be installed in a slightly larger area than the treatment area (i.e., 53,400 sf)
33	Thermal oxidation is included for the treatment of non-condensable vapors extracted
34	Liquid granular activated carbon (GAC) is included for the treatment of condensable vapors and liquids extracted
35	Unit gas prices are estimated at \$18/mmBTU
36	Unit power prices are estimated at \$0.12/kWh



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Cornell-Dubilier Electronics (CDE) Superfund Site
South Plainfield, New Jersey
General Assumptions, continued

Assumptions	
Cornell-Dubilier Electronics (CDE) Superfund Site	
37	Unit caustic prices are estimated at \$2.60/gallon
38	Unit GAC costs with disposal are estimated at \$2.2/lb
39	Unit NAPL disposal costs are estimated at \$1/lb
40	2 men are on site during drilling
41	2 drill rigs are included
42	The estimated drilling rate per day is 200 ft/day
43	2 men are included during site operations
44	Power drop, transformer and running of any lines are excluded
45	Removal of heaters, wells and vapor cap is excluded
46	Site restoration is excluded



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